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TDA-RCA Capsule Pipeline Project

Capsule Pipeline System Analysis Part 2
Capsule Pipeline Techno-Economic Simulation Model

edited by
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Alberta
RESEARCH

TDA-RCA CAPSULE PIPELINE PROJECT

CAPSULE PIPELINE SYSTEM ANALYSIS

PART II

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PREFACE

Transportation costs constitute a significant portion of the total cost of marketing bulk and anticipated large-volume manufactured commodities produced in Alberta. The work on capsule pipelining at the Research Council of Alberta (RCA) is directed towards developing a solids transportation system which can offer cheaper tariffs to bulk and other commodities (cans, etc.) than the presently existing modes of transportation.

Beginning in 1959, the first several years of research made significant progress towards developing and understanding the principles involved in pipelining solid bodies. Also an appreciation was gained of the type of supporting equipment that would be needed to operate a total capsule pipeline system. In 1967-68 the Solids Pipeline Research and Development Association (SPRDA) sponsored a feasibility study jointly with the Government of Alberta and the Federal Department of Industry. The experimental data were generated by RCA in a 4 inch pipeline loop and outside consultants carried out economic and technical analyses. The general conclusion was that based on the state of technology at that time, capsule pipelining would be an economically viable method of transportation in some instances. In 1971 a three-year Transportation Development Agency (TDA) sponsored program was launched with the objective of defining as closely as possible the effect of all of the related parameters on the hydrodynamics of a capsule pipeline system and to produce reliable design equations relating to commercially sized pipe. This study has led to the development of methods for calculating pressure gradients in capsule pipelines. The results were reported in a three-volume project report (RCA Information Series No. 63).

The System Analysis was undertaken as a TDA-RCA cost-shared program towards the end of this hydrodynamic study to evaluate the state of technology for the entire capsule transportation system and to provide, as a tool, a computer model which could be used for preliminary economic evaluation of potential applications for capsule transportation. These detailed objectives were defined in the application submitted to the Federal Treasury Board which in part, reads:

The Transportation Development Agency is sponsoring a three-year research project in capsule pipeline technology, which is scheduled for completion at the end of fiscal year 1973-74. It has successfully addressed itself to experimental and analytical work on instrumented pipelines of various sizes, with the object of furthering the understanding of the hydrodynamics of moving commodities in capsule form through pipelines. As a result, more reliable judgements of the economics involved, and realistic assessment of the suitability to Canadian applications of capsule pipelines may now be made.

At the conclusion of this project, it will be important to be able to assess the viability of a capsule pipeline system with sufficient confidence to justify committing capital investment for a commercial operation. This proposal concerns the studies necessary for this assessment which consists of two parts: one which will qualify, and the second, quantify the factors involved.

Part I, will identify all major physical components of a system, the state-of-the-art of each and the R & D time and expense necessary to attain operational viability. It will assign priorities to R & D work required and produce a critical path diagram for the same.

Part II, will establish a computer simulation model to provide a total economic evaluation of any potential application before development work is commissioned. It will identify all the parameters and variables peculiar to capsule pipelining and reduce them to economic terms. The model will, thus, be designed to optimize systems under consideration and will make it possible to assess the potential of capsule pipelining in more realistic terms than has been possible to date. It will be an invaluable tool for economic and technical trade-off analyses and permit comparisons with other transport modes.

The information produced by simulation models and application studies is needed to provide the necessary information for industry and potential users to assess the viability of solids pipelining using the capsule mode. It will also increase the chances that a successful application evolves from the research expended to date. Close liaison on the work will be maintained with in-house TDA studies in this field and will be overseen by the Capsule Pipeline Technical Review Committee which is chaired by TDA and has members from industry. The results of the analyses together with data from appropriate site-specific application studies undertaken using the techno-economic computer simulation model will be fully documented in a report to TDA.

The final agreement signed between the TDA and the RCA stipulates the scope of the analysis as follows:

Part I: Capsule Pipeline R & D Requirements

1. Describe all major component areas and subdivisions thereof, then assess the state-of-the-art in each area.

2. Determine the R & D required in each area in terms of technological development and innovation.

3. Determine the time and money needed to carry out the necessary R & D and assign priorities to R & D work required.

4. Produce a critical path diagram for the required R & D work for different end uses:

   a) assuming a fixed date of completion for all work;

   b) assuming that the necessary R & D is carried out in a sequential order of importance permitting decision on further funding as each step progresses.

Part II: Developing Capsule Pipeline Techno-Economic Simulation Model

1. Identify all parameters and variables in total system (enhancing existing macro-technical model developed by TDA).

2. Determine relationship of each variable with all others in system.

3. Construct flow diagram and identify logic.

4. Develop and debug computer simulation program.

5. Demonstrate utility of model through simulation of typical problem solutions.

6. Collect available data for candidate applications preparatory to undertaking site-specific studies to compare with other modes.

The study therefore fills two separate and distinct needs:

- to provide a summary of the areas in which technological experience is available and a basis for estimating additional development expenditures which are required;
- to provide a means for generating preliminary estimates of the capital requirements and operating costs of specific transportation proposals.

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PART II

CAPSULE PIPELINE TECHNO-ECONOMIC SIMULATION MODEL

INTRODUCTION

Significant advances have been made in explaining and quantifying the phenomena influencing the hydrodynamics of capsule pipelining (see TDA-RCA Project Reports 1 - 3, and Part 1 of this report). Concurrently, preliminary design work and the testing of prototypes have progressed to the point where initial estimates of capital and operating costs can be suggested for such operations as capsule manufacturing, pump bypass systems and capsule retrieval. Future development work will undoubtedly concentrate on exploring and solving the problems associated with transporting specific commodities as well as large scale testing of equipment. Before commissioning expensive and time consuming work in these areas it is imperative that a preliminary assessment of the economic viability of a proposed system be obtained, that the factors which have the greatest influence on cost be identified, and that some understanding be gained of how the various options in system design affect operating and capital costs.

In order to carry out these evaluations in an efficient and consistent manner, a computer model of capsule pipelining systems has been developed. It has been designed with simplicity, flexibility and ease of use in mind. Where relationships and data are known they have been incorporated in the program. For applications where physical and experimental data or the design and cost of facilities are not known, this information must be generated externally and introduced as input to the model.

The computer program performs the lengthy hydrodynamic calculations, produces a preliminary cost estimate and evaluates the economics for the chosen commodity candidates for capsule pipelining. The hydrodynamics and economics program sections are adaptable to all applications, whereas the costing section is peculiar to each commodity.

To simplify input and operation for the costing program the pipeline system is divided into four cost centers; pipeline origin, pipeline, pump and pump bypass stations and pipeline terminal. Commodities for which costing programs are presently included are potash, sulfur, coal, iron ore and solid waste. Others will be

added as required, unless they can be approximated by treating them as a commodity already incorporated. These programs allow various throughputs to be considered and the capital and operating cost estimates include equipment, land, labour, fringe benefits, property taxes, etc. Cost equations derived from these estimates were entered into the program for each of the four cost centers for the commodities considered.

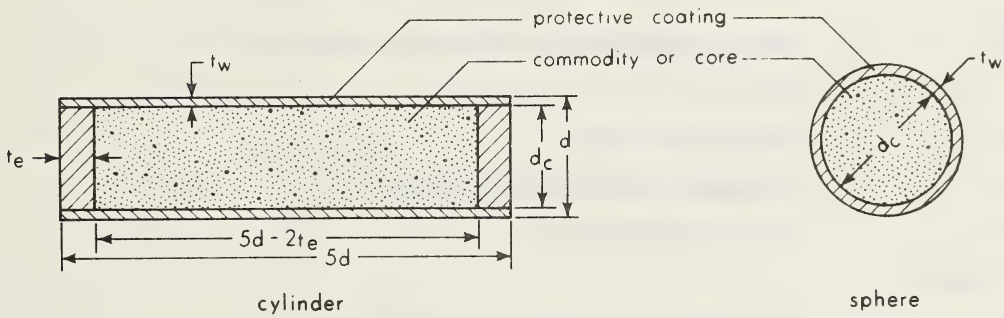
A discounted cash flow rate of return analysis has been chosen as the economic indicator. This method is widely accepted in industry and it is generally agreed that it most accurately reflects the true financial return on investment.

The uncertain data base in many areas and the use for which the program is intended required many simplifying assumptions to be made, both in the costing and economic evaluation methods. As further technical research and development generates additional information, more sophisticated and precise procedures can be incorporated into the program.

Capsule Pipeline Techno-Economic Simulation Model

MODEL DESCRIPTION

The program is basically composed of three parts: the hydrodynamics or hydraulics of the pipeline system, an estimate of the capital cost and operating expenses associated with the proposed application, and a discounted cash flow economic analysis of the project. These three parts are all affected by the shape of the capsule and its component parts. In order to be general the program can handle different protective coating materials and thicknesses. For cylindrical capsules it is possible to have a different thickness and/or a different material for the end coating than for the wall coating. The capsules have the sectional shape illustrated with an assumed overall length of five times its outside diameter for the cylinders.



Thus: $d_c = d - 2\,t_w$, and since $k = d/D$

$$d = kD \text{ and } d_c = kD - 2\,t_w$$

The subscript "c" always refers to the core of the capsule which is assumed to be the main payload commodity, although the coating itself also could be payload.

1. Hydrodynamics

Nomenclature:

D	inside pipe diameter (in.)
D_o	outside pipe diameter (in.)
$\Delta P/L$	pressure gradient (psi/mi.)
F	fractional linear line fill of capsules
k	capsule to pipe diameter ratio
L	pipeline length (mi.)
P	maximum allowable working pressure for system (psi)
P_s	pump suction pressure (psi)
Re	pipe Reynolds number $\frac{V_b D}{\nu}$
Re_{an}	Reynolds number in the annulus space between capsule and pipe wall $\frac{V_{an} D(1 - k)}{\nu}$
S	minimum yield strength of pipe steel used (psi)
t	thickness (in.)
V	velocity (ft./sec.)
W	throughput (units specified in text)
Y	elevation change (ft.)
Greek	
ν	liquid kinematic viscosity (ft. /sec.)
ρ	liquid specific gravity
σ	solids specific gravity
Subscripts	
an	annulus
b	bulk
c	commodity or capsule core
e	end coating (or cap) of cylindrical capsules
f	carrier liquid
w	wall coating of capsule
y	elevation change

Abbreviations used in text

BPD	barrels (42 U. S. gallons) per day
DP	pump discharge pressure (psi)
HHPPS	hydraulic horsepower per station
IHP	installed horsepower
IHPPS	installed horsepower per station
MMTPY	millions of tons per year
N	number of pumping stations
SS	station spacing (miles)
TPY	tons per year

Input required:

If the capsules are to be coated, then the thickness of the coating (t_w and t_e) is input along with the specific gravities (σ_w and σ_e). Other input normally required is: L, $\pm$Y, W_c, V_c, k, F, S, P, $(\Delta P/L)_c$, ρ, σ_c, ν, and cc (computer capsule coding, i.e. cylindrical or spherical). A site specific case study provides the pipeline length (L) and elevation change ($\pm$ Y), the liquid parameters of specific gravity (ρ) and viscosity (ν) and the commodity parameters of specific gravity (σ_c) and throughput (W_c). The yield strength of the steel used in the pipe (S) is available in 35000, 42000, 46000, 52000 and 60000 psi. The maximum permitted working pressure (P) could be due to equipment, capsule strength or pipeline constraints. The diameter ratio (k) for cylindrical capsules will be limited by practical capsule lengths and pipeline bend radii (cf. Fig. 2, Ch. 1 of Part I of this report). The linear linefill of capsules (F) would desirably be 100% but may be limited to a lesser value by the capsule manufacturing procedure or the injection and pump bypass devices. Linear linefills of 100% for cylindrical and spherical capsules have been attained with laboratory scale (5/8" and 1" respectively) rotary pump bypass devices (cf. Part I of this report). These types of bypass systems could also serve as injection devices. The capsule code (cc) is included to direct the computer to spherical or cylindrical capsule calculations. The remaining inputs are the capsule velocity and capsule pressure gradient.

Capsule Velocity and Capsule Pressure Gradient:

The capsule pressure gradient and capsule velocity are dependent on one another and vary with the pipeline and capsule physical properties. The pressure gradient is the single most important input parameter in the design of a pipeline system, and there are a number of ways that it and its corresponding velocity may be obtained. These have been discussed in TDA-RCA Phase 3 Report. They are summarized here with emphasis on accuracy and the order does not coincide with that of the Phase 3 Report.

(i) The most accurate method is to obtain measurements from a full scale prototype pipeline, having the capsules, pipe and operating conditions exactly as they would be used in the actual application.

(ii) A close estimate may be obtained by interpolation of existing data on similar pipe and capsules with the same dimensions and physical properties as provided in Chapter 3 of the TDA-RCA Project Phase 3 Report. These data are correlated in Chapter 5 of the same report.

(iii) An analytical method for cylindrically shaped capsules utilizing a friction coefficient is described in Chapters 2 and 4 of the TDA-RCA Project Phase 3 Report. It requires the experimental measurement of the friction coefficient between the capsule and pipe wall with the interface wetted with a thin film of the carrier liquid. This coefficient varies with velocity as well as with material and surface finishes.

Chapter 6 of the same report describes an analytical method for spherically shaped capsules. The capsule pressure gradient is defined as a function of the liquid pressure gradient for smoothly machined spheres. It is then adjusted for the degree of out-of-roundness, which, at the present has to be determined experimentally.

The data obtained at a constant velocity may have to be adjusted for a different capsule specific gravity, a different liquid viscosity, or a different diameter ratio than that measured, as discussed for cylinders in Chapter 5 of the TDA-RCA Project Phase 3 Report.

The capsule velocity and capsule pressure gradient are supplied as input data for the system being considered. Re-running of the program with data covering a practical range of capsule velocities will indicate the optimum conditions.

Options:

Cylindrical or spherical capsules may be considered by entering a 0 or a 1 respectively for cc (capsule coding) in the input. These capsules in turn may be coated, in which case the coating thickness and specific gravity of the wall and end plate material (if applicable) is input. The diameter ratio input refers to the outside capsule diameter

including coating thickness, and commodity throughput (W_c in MMTPY) refers to the capsule core. The computer flowcharts are the same for cylindrical or spherical capsules but the calculation equations sometimes differ.

Other options available in the computer program, which apply to any type of capsule are:

1. If the desired commodity throughput is known, the required pipe diameter and wall thickness are determined. This would be the usual situation.
2. If pipe diameter is input, the throughput is calculated.
3. If pipe diameter and throughput are known, the capsule velocity is calculated.

Options 1 and 2 require a capsule velocity input as a starting point for the computer. After the pipe is sized the velocity is corrected for option 1 and remains unchanged for options 2 and 3. The capsule pressure gradient input must correspond to this actual or final velocity. The slope of the capsule pressure gradient versus capsule velocity for practical velocities is small for cylinders, but large for spheres, so caution is necessary if considering spheres in option 1.

Options 2 and 3 apply when a pipeline exists and is to be considered for conversion to the transportation of solids. This would be a rare case since capsule pipeline weld, bend, telescoping and possibly pressure specifications would differ from a liquid pipeline. In these two options the calculated outside diameter must be checked against the actual diameter to determine if the pipe wall thickness is adequate.

Assumptions:

1. Existing codes (C. S. A. Standard Z 183 - 1967 and U. S. A. S. Code B 31.4 - 1966) for liquid carrying pipelines have been assumed applicable since none exist specifically for capsule pipelines.
2. For all calculations it is assumed that the pipeline operates 350 days per year.
3. For cylindrical capsules, the capsule length is assumed to be five times its outside diameter.

4. It is assumed that the capsule gradient loss or gain on slopes is the weight component acting in the axial direction of the pipeline. This does not take into account the slight friction reduction caused by the decreased normal force on slopes that would result in a lesser pressure gradient.

Computer Calculations:

A. Inside Diameter

For cylinders:

$$D = \left[194.2\, W_c / (\sigma_c \quad V_c \quad k^2 \quad F)\right]^{\frac{1}{2}}$$

For spheres:

$$D = \left[291.3\, W_c / (\sigma_c \quad V_c \quad k^2 \quad F)\right]^{\frac{1}{2}}$$

These equations provide an approximate value for D only, since the coating thickness has been assumed to be negligible.

When considering coated capsules it is more convenient to express the equations in terms of the capsule diameter and the commodity diameter. Using the definition of diameter ratio $k = d/D$, the capsule diameter $d = kD$, and the commodity diameter $d_c = k\,D - 2\,t_w$ as explained earlier. Values for k and t_w are input, whereas D is either input or calculated.

If pipe inside diameter (D) is input, then the commodity throughput is calculated.

For cylinders:

$$W_c = 0.0051484\ d_c^2\ F\ \sigma_c\ V_c\ (d - 0.4\ t_e)/d \qquad \text{MMTPY}$$

For spheres:

$$W_c = 0.003432\ d_c^3\ F\ \sigma_c\ V_c\ /d \qquad \text{MMTPY}$$

Pipe wall thickness:

$$t = 1.39\, P\, D/(2S - 2.78\, P) \qquad \text{inches}$$

This required wall thickness determination is based on U.S.A.S. Code B 31.4 - 1966 and applies to type "A" construction for pipe having a longitudinal joint factor of unity. This includes most types of pipe.

Outside diameter:

$$D_o = D + 2\,t$$

The computer scans the table of standard pipe sizes (Appendix B) and chooses the next size larger D_o and the next size larger t.

Strength check:

The pipe must be capable of withstanding the specified maximum allowable working pressure (P) which is input.

i.e. $$\frac{2\,S \cdot t}{1.39\,D_o} \geqslant P$$

If the calculated value $< P$, then the computer chooses the next larger t from the same D_o table and re-checks the working pressure until the condition is met.

Diameter and velocity correction:

The pipe inside diameter must be corrected for the D_o and t chosen by the computer,

$$D = D_o - 2\,t$$

and this in turn alters the capsule velocity for a given throughput of commodity. If the capsule coating is appreciable, the calculated velocity may be greater than the initial velocity used as input.

Rearranging the throughput equations:

For cylinders:

$$V_c = 194.2\, W_c d/(d_c^{\,2}\,(d - 0.4\,t_e)\,\sigma_c F)$$

For spheres:

$$V_c = 291.35\, W_c\, d/(d_c^{\,3}\, \sigma_c\, F)$$

B. Capsule Specific Gravity

For coated capsules the capsule specific gravity will differ slightly from the commodity specific gravity depending on the coating thickness. The capsule pressure gradient is very dependent on the buoyed capsule specific gravity ($\sigma - \rho$) so the computer calculates the actual specific gravity and the user may then correct or input the corresponding capsule pressure gradient for this specific gravity and calculated capsule velocity.

For cylinders:

$$\sigma = (0.4\ d_c^{\,2}\ t_e\ (\sigma_e - \sigma_c) + (d^2 - d_c^{\,2})\ d\ \sigma_w + d_c^{\,2}\ d\,\sigma_c)/d^3$$

For spheres:

$$\sigma = (d_c^{\,3}\ \sigma_c\ + (d^3 - d_c^{\,3})\ \sigma_w\ )\ /d^3$$

C. Calculation of Bulk Velocity*

The bulk velocity V_b is defined as the total volumetric throughput divided by the internal cross sectional area of the pipe.

For cylindrical and spherical capsules:

assuming turbulent flow in the annulus:

$$V_b = k\, V_c + 0.046\ (1 - k^2)\ \left[\frac{(\Delta P/L)_c\ \ (D - kD)^{1.25}}{\rho\, \nu^{\,0.25}} \right]^{0.571}$$

check Reynolds number in annulus:

$$Re_{an} = \frac{D\ (1 - k)\ \ (V_b\ - k\ \ V_c\,)}{12\ \ (1 - k^2\,)\ \ \nu}$$

* Chapter 7 of the TDA-RCA Project Phcse 3 Report

if $Re_{an} > 1000$, V_b is correct

if $Re_{an} \leq 1000$,

$$\text{then } V_b = k\,V_c + (1 - k^2) \left[\frac{(\Delta P/L)_c \quad (D - k\,D)^2}{19.6 \times 10^4 \; \nu \, \rho} \right]$$

D. System Pressure Drop

The system pressure drop is the total pressure gradient multiplied by the pipeline length. The total gradient is composed of the gradient due to the liquid multiplied by the linear fraction of the line that is occupied by liquid only (a), plus the gradient due to the capsules multiplied by the linear fraction of line that is filled with capsules (b), plus the algebraic sum of the gradient due to elevation change (c).

i.e. $(\Delta P/L)_b = (\Delta P/L)_f \;(1 - F) + (\Delta P/L)_c F + (\Delta P/L)_y$ psi/mile

(a) Liquid pressure gradient:

Capsule pipelines over six inches in diameter will likely be required to obtain economically feasible throughputs. This, and the fact that the pipeline contents must be moved at velocities higher than the capsule threshold velocity will result in the system being operated in the turbulent flow regime. The program does in all cases check the Reynolds number and if laminar flow is indicated (i.e. $Re \leq 2000$) a message indicating that condition is printed out and the liquid pressure gradient is calculated using the friction factor for laminar flow. If the flow is turbulent no message is printed out since this is considered the normal situation. There are several empirical equations available for this flow regime, and they were tested and the results compared with the Darcy equation using friction factors presented by L. F. Moody[1] for a pipe roughness (ϵ) of 0.00015, which is valid for new clean commercial steel pipe. A capsule pipeline should not have the usual problems of scale build-up or deposits often encountered in liquid pipelines resulting in a varying pipe roughness factor. The equation of Drew,

1.) L. F. Moody, "Friction Factors for Pipe Flow." Trans. A.S.M.E. Vol. 66, No. 8, 1944, p. 671.

Koo and McAdams[2] fits the friction behaviour very well over the velocity range considered.

Darcy equation:

$$\left(\frac{\Delta P}{L}\right)_f = \frac{62.43 \times 12\,(5280)}{2\,(32.17)\;144}\; f\,\rho V_b^{\,2}/D = 427\, f\,\rho V_b^{\,2}/D \quad \text{psi/mile}$$

Reynolds number:

$$Re = \frac{V_b\, D}{12\,\nu}$$

Friction Factor:

for laminar flow (i.e. if $Re \leq 2000$): $f = \dfrac{64}{Re}$

for turbulent flow (i.e. if $Re > 2000$), the equation of Drew, Koo and McAdams is used: $f = 0.0056 + 0.5\,Re^{-0.32}$

(b) Capsule pressure gradient $(\Delta P/L)_c$ is input to the program, cf. pages 7 - 8

(c) Pressure gradient due to elevation change:

The pressure change due to elevation is the head (elevation change) multiplied by the bulk specific gravity.

$$(\Delta P/L)_y = (62.43/144)\,(\pm Y)\;\rho_b\,/L \quad \text{psi/mile}$$

where the bulk specific gravity is defined as the total weight of capsules plus liquid in the line divided by the total volume of the line, thus

For cylinders:

$$\rho_b = \rho + \frac{F}{5\,d\,D^2}\Big[d_c^{\,2}\,(5d - 2\,t_e)\,(\sigma_c - \rho) + (2\,d^2\,t_e)\,(\sigma_e - \rho) + (d^2 - d_c^{\,2})\;5\,d\;(\sigma_w - \rho)\Big]$$

For spheres:

$$\rho_b = \rho + 2/3\,\frac{F}{d\,D^2}\Big[d_c^{\,3}\,(\sigma_c - \rho) + (d^3 - d_c^{\,3})\,(\sigma_w - \rho)\Big]$$

2.) Drew, Koo, and McAdams, "The Friction Factor for Clean Round Pipes." J.Am.Inst. Chem. Eng., Vol. 28, p. 56, 1932.

E. Pumping Station Requirements

The pump suction pressure, P_s, is input.

(a) Number required including one at the pipeline origin:

$N = (\Delta P/L)_b \; L \; / \; (P - P_s)$ and reported as the next whole number.

(b) Average or equidistant station spacing:

$$S\,S = L/N \text{ miles}$$

(c) Hydraulic HP required per station:

$$HHPPS = \frac{\pi D^2 \; V_b}{4 \times 550} \left(\frac{\Delta P}{L}\right) \; SS$$

(d) Installed HP per station:

The installed horsepower per station is the hydraulic horsepower divided by the station efficiency. The pumping station consists of a pump and motor and a by-pass system. Assuming 75% pump efficiency and a 70% rotary vane bypass efficiency nets a station efficiency of 52.5%. Thus the brake horsepower of the motor installed becomes:

$$IHPPS = HHPPS/0.525$$

Total horsepower installed

$$IHP = IHPPS \times N$$

(e) Carrier liquid throughput:

W_f = bulk throughput less throughput of capsules

$$= \frac{62.43 \, \pi \, 3600 \times 24 \times 350}{4 \times 144 \times 2000 \times 10^6} \; \rho_b \; V_b \; D^2 - W_c - \frac{(W_e + W_w)}{10^6}$$

where: W_e and W_w are in TPY

For cylinders:

$$W_f = 0.005148\,\rho_b\ V_b\ D^2 - W_c \left[1 + \frac{2\,t_e\ \sigma_e}{\sigma_c\ (5d - 2\,t_e)} + \frac{20\,d\,\sigma_w\ t_w\ (d - t_w)}{\sigma_c\ d_c^2\ (5d - 2t_e)}\right] \quad \text{MMTPY}$$

For spheres:

$$W_f = .005148\,\rho_b\ V_b\ D^2 - W_c \left[1 + \frac{(d^3 - d_c^{\ 3})\ \sigma_w}{d_c^{\ 3}\ \sigma_c}\right] \quad \text{MMTPY}$$

or in U.S. petroleum barrels per day:

$$\text{BPD} = 16310\ W_f\ /\ \rho$$

(f) Solids throughput:

1) End cap: (applies only to cylinders)

$$W_e = W_c \left[\frac{2\,t_e\ \sigma_e}{(5\,d - 2\,t_e)\sigma_c}\right] \times 10^6 \quad \text{TPY}$$

2) Wall material

For cylinders:

$$W_w = W_c \left[\frac{20\,d\ \sigma_w\ t_w\ (d - t_w)}{\sigma_c\ d_c^{\ 2}\ (5d - 2\,t_e)}\right] \times 10^6 \quad \text{TPY}$$

For spheres:

$$W_w = W_c \left[\frac{(d^3 - d_c^{\ 3})\ \sigma_w}{d_c^{\ 3}\ \sigma_c}\right] \times 10^6 \quad \text{TPY}$$

3) Total solids

$$W = W_c + \frac{W_e + W_w}{10^6} \quad \text{MMTPY}$$

(g) Pump Sizing:

1) The pump discharge pressure:

$$DP = (\Delta P/L)_b \quad SS + P_s$$

2) Pump Capacity:

The capsules are always being displaced by an equal volume of liquid in the rotary vane bypass device, thus the pump must be capable of handling the volume of liquid that is required to move the capsules plus an extra volume equivalent to that occupied by the capsules. This is the case with any pump bypass system envisaged at the present time. Thus:

$$\text{Flowrate} = 448.8 \left(\frac{\pi D^2}{4 \times 144}\right) V_b \qquad \text{USGPM}$$

2. Costing

In order to make the program convenient to use, that is, minimize the required amount of input data, the capital and operating costs were built into the program as mathematical functions of commodity or liquid throughput, or as a function of the horsepower requirements. In order to arrive at these equations, capital and operating cost estimates were determined for each commodity at different throughputs. The Hu Harries & Associates Ltd. report "An Economic Analysis of Capsule Pipelining" prepared for the Solids Pipeline Economic Study Association in June, 1968, provided the main source of information, especially for capsule fabrication costs. The Harries report considered site specific cases for the commodities potash, sulfur, coal and iron ore, at throughputs ranging from 1 to 10 million tons per year. These and solid waste are the commodities presently included in the program. However, the important option does exist to input actual capital and operating costs for a case rather than have the computer calculate them. It should also be noted that the data relating to other commodities can be added to the program as they become available.

General Comments:

(a) All built-in cost equations are in terms of 1973 dollars.

(b) No allowances are made for research or development costs associated with any of the mechanical devices or processes peculiar to capsule pipelining.

(c) Loading and unloading costs are included. This should be considered when comparisons are made with other modes where these costs may not be included.

(d) No start up costs have been included.

(e) Storage facilities sufficient to ensure a smooth continuous pipeline operation are charged to the pipeline. This includes one day's storage of the liquid at the pipeline origin and terminal, one day's storage of the commodity at the origin and two day's storage at the terminal between the end of the pipeline and the reconstitution plant. This storage capacity could readily be changed without altering the system

economics noticeably since the cost only represents a small fraction of the total capital investment.

(f) It is assumed that all commodities are delivered to the pipeline in a form ready for encapsulation and it is the pipeline operator's responsibility to reconstitute the commodity to its delivered state, with the exception of sulphur, which will be supplied to the origin in molten form and delivered in the solid state at the pipeline terminal.

(g) The capital cost at the pipeline origin and terminal is assumed independent of capsule coating thickness.

(h) The external input required for costing is:

C_L	carrier liquid cost per thousand imperial gallons ($)
C_e	end cap material cost per ton ($)
C_w	wall coating material cost per ton ($)
GF	geographic factor for costing of the pipeline.

All capital and operating cost items for the entire pipeline system have been grouped into four cost centres. These cost centres and associated components are listed below.

Cost Centres:

A. Pipeline Origin
- Carrier & commodity storage
- Encapsulation
- Land
- Buildings
- Pipeline control centre

B.. Pipeline
- Pipe
- Right of Way
- Installation

C. Pump and Bypass stations

Vane bypass device

Booster pump

Control and automation equipment

Land

Buildings

D. Pipeline Terminal

Capsule-liquid separation

Commodity reconstitution

Carrier liquid treatment

Storage facilities

Land

Buildings

The capital cost items include such items as land, buildings, structures, machinery, tanks, pipe, fittings, valves, pumps, motors, office and control equipment, vehicles, etc. The operating costs include a level of repair and maintenance necessary to ensure that the system components will perform continuously over the assumed pipeline life. This approach was used rather than attempting to estimate the life of equipment presently under development or equipment having no performance history in capsule pipelining applications. Other expense items such as taxes, power and utilities, salaries and wages, carrier liquid, encapsulation materials, supplies, rentals, administration, insurance, etc., have been included in the operating costs.

Unless otherwise stated, estimates were based on property taxes at 0.75% of assets at cost, land at $1300/acre, insurance at 0.1% of assets at cost, power at 0.6¢/kwh, process water at 32¢/1000 gallon, average labor at $5/hour, and supervisory staff at $10/hour.

Commodities Considered:

1. Potash

Standard grade potash with a bulk specific gravity of 1.6 is received at the pipeline origin. It is processed ('delumped')and then packaged in plastic film to give cylindrically shaped capsules. These cylinders can be transported in a water or oil medium. The throughputs considered were in the range of 1.5 to 9 million tons per year.

2. Sulfur

Molten elemental sulfur is received and cast into cylindrical or spherical capsules with a specific gravity of 1.8. These capsules may be coated (non-returnable container) or uncoated (no container), and transported in a water or oil medium. Sulfur throughputs of 1 to 3 million tons per year were considered.

3. Coal

Powdered coal is mixed with water and extruded into cylindrical capsules of the desired length. The resultant cylinder has a specific gravity of 1.23 and is transported in an oil medium with no protective coating. Throughputs of 1 to 5 million tons per year were considered.

4. Iron

Iron ore is received in granular form no coarser than that normally pelletized. The ore is moistened with water, mixed with a binder (1% Bentonite), compressed into spheres and sintered. The resulting spheres have a specific gravity of 4.5 and may be transported in a water or oil medium with no protective coating. Iron ore throughputs of 6 to 10 million tons per year were considered.

5. Solid Waste

Solid waste is received from the transfer station in a state ready for forming into cylindrical capsules in a hydraulic press. It is preferrably compressed to the same density as the carrier liquid, which in all probability will be water. The capsules may be coated, or left uncoated. If a binder is necessary, the cost of it is added to the liquid cost or the commodity tariff to account for it in the economic analysis. Solid waste throughputs of 0.2 to 0.7 million tons per year were considered.

Evaluation of the economics of capsule pipelining for commodities other than these five can be estimated if their processing is not greatly different as cost differences between commodities are due mainly to differences in capsule preparation costs. Capsule density and surface will affect the pressure gradient and hence the pumping costs but these are accounted for separately. Capsule fabrication costs would be similar for most powdered material being transported in plastic bags, for most molten materials used to form cast capsules, for most materials that would be extruded as paste capsules and for most materials requiring molding and sintering. In the program, commodities other than those listed can be estimated by entering the appropriate specific gravity and the code of the commodity with a similar capsule fabrication process to the commodity being considered. Case 3 in Appendix C is an example of this procedure in which the economic analysis is made for shipping powdered sulfur in plastic bags by using the potash figures (i.e. entering the potash code and the specific gravity for powdered sulfur).

A. Pipeline Origin

The pipeline origin cost centre includes everything prior to the pipeline injection and first pumping station. Since the injection system would be similar to a bypass facility (e.g. the rotary vane bypass device considered here) it was included in that cost centre.

Considerable storage would probably be required at the pipeline origin for the commodity owner to account for seasonal production rates and demand fluctuations. This storage is needed by him regardless of transportation mode, although it may mean relocating existing storage. However, to ensure a smooth continuous pipeline operation, one day's storage of liquid and commodity is included and charged to the pipeline, cf. page 18 (e).

With these assumptions, cost estimates were examined and expressed as a function of commodity throughput and carrier liquid cost, in terms of thousands of 1973 dollars.

Capital Cost (in thousands of 1973 dollars) = Table Value

COMMODITY		MODE	
		No Container	Non-returnable Container
Potash:	in Oil		$3743\ W_c^{.72}$
	in Water		$3743\ W_c^{.72}$
Sulfur:	in Oil	$5335\ W_c^{.54}$	$5600\ W_c^{.54}$
	in Water	$5335\ W_c^{.54}$	$5600\ W_c^{.54}$
Coal:	in Oil	$3940\ W_c^{.49}$	
Iron Ore:	in Oil or Water	$2715\ W_c^{.56}$	
Solid Waste:	in Water	$3664\ W_c^{.60}$	$4211\ W_c^{.60}$

Operating Cost per Annum (in thousands of 1973 dollars) =

$200\ C_f W_f / \rho$ + table value + protective coating material cost (C_m)

(See definition below)

COMMODITY		MODE	
		No Container	Non-returnable Container
Potash:	in Oil		$560\ W_c^{.64}$
	in Water		$560\ W_c^{.64}$
Sulfur:	in Oil	$936\ W_c^{.59}$	$1050\ W_c^{.47}$
	in Water	$936\ W_c^{.59}$	$1050\ W_c^{.47}$
Coal:	in Oil	$816\ W_c^{.49}$	
Iron Ore:	in Oil or Water	$869\ W_c^{.68}$	
Solid Waste:	in Water	$550\ W_c^{.60}$	$632\ W_c^{.60}$

Protective coating material costs apply to non-returnable containers.

$C_m = (W_e C_e + W_w C_w) / 1000$

Note: There is no allowance included for any special sulfur treatment to increase cast strength or decrease dusting hazards.

C_f is the cost of the carrier liquid input to the program. It varies dependent on whether oil or water is used as a carrier liquid.

In a preliminary estimate, the cost difference between manufacturing sulfur cylinders or spheres can be ignored. Although about 7.5 times as many spheres are required to produce the same volume as the corresponding cylinders for the same throughput, spheres are easier to coat, cool and handle at the pipeline origin. An increase of 100% in the capital cost of encapsulation does only increase the capital requirement by approximately 8%.

B. Pipeline

It has been assumed that the life, capital cost and maintenance of a capsule carrying pipeline are comparable to a liquid pipeline.

From data published in the August 13, 1973 issue of "The Oil and Gas Journal," a five year (1969 to 1973, inclusive) average pipeline cost equation was determined as a function of pipe weight based on the assumption that X-52 pipe was used. The pipe weight in turn can be expressed in terms of pipe diameter and wall thickness. This cost equation includes right-of-way, material and labour for liquid carrying pipelines. No additional allowance was made for capsule carrying pipelines as the pipe itself accounts for 60% to 80% of the cost and is included by considering pipe wall thickness and inside diameter. The clean inside pipe joints required for capsule pipelining are commonly used in conventional pipeline systems. It is not uncommon for pipeline costs to vary ± $15,000 per mile from the average, mainly due to geographic location of the pipeline, that is, topography as well as proximity to pipe supply, manpower and equipment sources, etc. Therefore, a geographic factor (GF) input option is included. This factor may range from 2 to 3 through rugged Alberta-British Columbia mountains, to as high as 5 for parts of a trans-Alaska pipeline. The resulting capital cost (Cc) equation in terms of thousands of 1973 dollars is:

$$Cc = L \left[36.13 + 14.45\, t \quad (D + t\ ) \right] \quad GF$$

The operating cost (Co), based on the following assumptions; taxes at 0.75% of capital investment, maintenance and repairs at 0.25% investment, and insurance at 0.1% of investment, becomes:

$$Co = 0.011\ Cc$$

C. Pump and Pump Bypass Station

It is assumed that the rotary vane pump bypass device can be used for all cases of capsule pipelining, although the device has been demonstrated only in two laboratory-scale models accommodating spherical or cylindrical capsules at a 100% linear line fill. The pump bypass and capsule phasing system, excluding the pump, has been assumed to cost $300 per installed horsepower (IHP) with an efficiency of 70%. The pump is assumed to have an efficiency of 75% and to cost $200 per installed horsepower including fittings, land, etc.

Rather than assuming a stand-by pump and pump bypass equipment at each station, allowance has been made for one fully unitized portable set for every five stations. The allowance for this was $400 per horsepower.

The resulting capital cost equation in thousands of 1973 dollars is:

$$Cc = 0.58 \text{ (IHP)}$$

The annual operating costs based on taxes at 0.75% of investment, building maintenance at 5% of cost, equipment repairs at 10% of cost, power at 0.6¢ per kwh, salaries and wages at $40,000 per station, and insurance at 0.1% of total assets, resulted in

$$Co = 0.153 \text{ (IHP)}$$

D. Pipeline Terminal

The pipeline terminal includes everything beyond the end of the pipeline, i.e. separation, storage, and recovery of the liquid and commodity.

Commodity-liquid separation consists of a roller conveyor system or a steel mesh conveyor at the pipe exit, and a catch pan for the liquid with a float controlled pump and motor unit, or simply gravity, to feed it to a storage tank, capable of holding one day's throughput. The liquid storage cost was doubled to allow for any treatment that may be required.

The resulting cost equations used for separation, liquid storage and treatment in thousands of 1973 dollars are:

$$Cc = 196\, W_f^{0.27}$$

$$Co = 29.3\, W_f^{0.35}$$

Two days of commodity storage is provided for between the end of the pipeline and the reconstitution plant to avoid pipeline shutdown in the event of temporary plant closure. For protection against the elements and for aesthetic and environmental reasons, shelter is provided at \$10 per square foot of floor and \$20,000 per acre of land. The resulting capital cost in thousands of 1973 dollars for commodity storage is:

$$Cc = W_c \left[33 + 350/\sigma\right]$$

Operating costs for the storage area are included in the reconstitution plant figures.

The commodity reconstitution or recovery plant transforms the commodity back to its delivered form, with the exception of sulfur which is supplied to the pipeline in the molten state and delivered as a solid. The moisture content of coal is lowered from 30% to 5% with only half of this cost being charged to the pipeline since this commodity normally requires drying at the mine in any event.

Combining these costs results in the following total (in thousands of 1973 dollars):

$$Cc = 196\, W_f^{.27} + \text{Table Value}$$

COMMODITY		MODE	
		No Container	Non-returnable Container
Potash:	in Oil		$480\, W_c^{.81}$
	in Water		$410\, W_c^{.86}$
Sulfur:	in Oil		$589\, W_c^{.57}$
	in Water		$510\, W_c^{.60}$
Coal:	in Oil	$990\, W_c^{.61}$	
Iron Ore:	in Oil	$390\, W_c^{.69}$	
	in Water	$330\, W_c^{.69}$	
Solid Waste:	in Water	$165\, W_c^{.60}$	$185\, W_c^{.60}$

$$Co = 29.3\, W_f^{.35} + \text{Table Value}$$

COMMODITY		MODE	
		No Container	Non-returnable Container
Potash:	in Oil		$56\, W_c^{.75}$
	in Water		$54\, W_c^{.74}$
Sulfur:	in Oil		$91\, W_c^{.78}$
	in Water		$89\, W_c^{.78}$
Coal:	in Oil	$630\, W_c^{.90}$	
Iron Ore:	in Oil	$76\, W_c^{.33}$	
	in Water	$73\, W_c^{.33}$	
Solid Waste:	in Water	$36\, W_c^{.60}$	$40\, W_c^{.60}$

The above cost estimates do not account for any difference in the handling of spheres or cylinders. The terminal capital and operating costs are insignificant relative to the total cost of the system, and for this reason, only preliminary estimates were developed.

3. Economics

The basis for the economic evaluation of a specific capsule pipelining application is a simplified discounted cash flow rate of return analysis. This type of calculation requires knowledge of the net cash flow accruing each year from the start of construction.

During the period of construction, the net cash flow will be negative and represents the capital investment. During the operating life of the project the annual cash flow represents the revenue from the operation less operating expenses and taxes. The discounted cash flow rate of return is defined as that interest rate which makes the present value of positive cash flows equal to the present value of the negative cash flows. Stated differently it is the interest rate at which the company's investment is repaid by proceeds from the project. The present value of any cash flow is considered to be its value at the beginning of the first year of operation after being either discounted or inflated by the interest rate.

Computational Procedure:

Estimates of the fixed capital requirements and the annual operating expense are carried forward from the costing subroutine. The external input data required by the program is detailed below:

1) CCA - the average capital cost allowance to be used in calculating depreciation deductions for tax purposes. This capital cost allowance is applied annually on a declining balance.
2) NYC - the number of years estimated for construction of the capsule pipeline system.
3) LIFE - the anticipated useful life of the project.
4) TR - the effective corporation tax rate which is to be applied to taxable income.
5) TARRC - the expected commodity tariff expressed in dollars per ton of commodity transported.
6) TARRL - a tariff which may be realized from the movement of a useful carrier liquid, expressed as dollars per 1000 Imp. Gal. of liquid.

7) TARRE – a tariff realized from the sale of end cap material at the terminal in dollars per ton of end cap material.

8) TARRW – a tariff from the sale of wall coating material in dollars per ton of wall material.

Computations within the program proceed as follows. Assuming that the pipeline begins operation in say 1980, the annual operating expense estimate is increased from its 1973 base by 8 per cent per year to account for inflation. Thereafter all annual expenses throughout the life of the project are held constant. If it is assumed that tariffs would increase, then the use of constant annual operating costs will not affect the net cash flow to the company. The capital cost estimate is divided evenly over the suggested period of construction prior to the 1980 start-up point. The capital cost estimate is also inflated at an annual rate of 8 per cent from 1973 to the year it was spent. An additional investment in working capital, equal to three months operating expenses is also required when operation begins.

Next, the program calculates the gross revenue realized by the company according to the commodtiy and liquid carrier tariffs that have been input. This revenue also is assumed to be constant throughout the project life except during the first year of operation where it is assumed that only 50 per cent of the design capacity will be achieved. Operating costs are lower in the first year because of reduced requirements of encapsulating material.

The program then calculates the annual depreciation charge to be deducted for tax purposes. The book value declines according to the capital cost allowance deduction and each succeeding annual deduction is based on this declining book value. A full deduction of the remaining book value is taken at the end of the last year of operation. At this time, the working capital is also recovered.

Profit before taxes is equal to the total revenue less depreciation, operating expenses and any previous loss on the operation. Provision is made for carrying losses forward until they are eliminated. Taxes payable and net income are computed by applying the corporate tax rate to the before-tax-profit. The net cash flow for any year is the total revenue less operating expenses and taxes. If the revenue is not sufficient to cover operating expenses, then the cash flow is negative which means that additional investment is needed to continue operation.

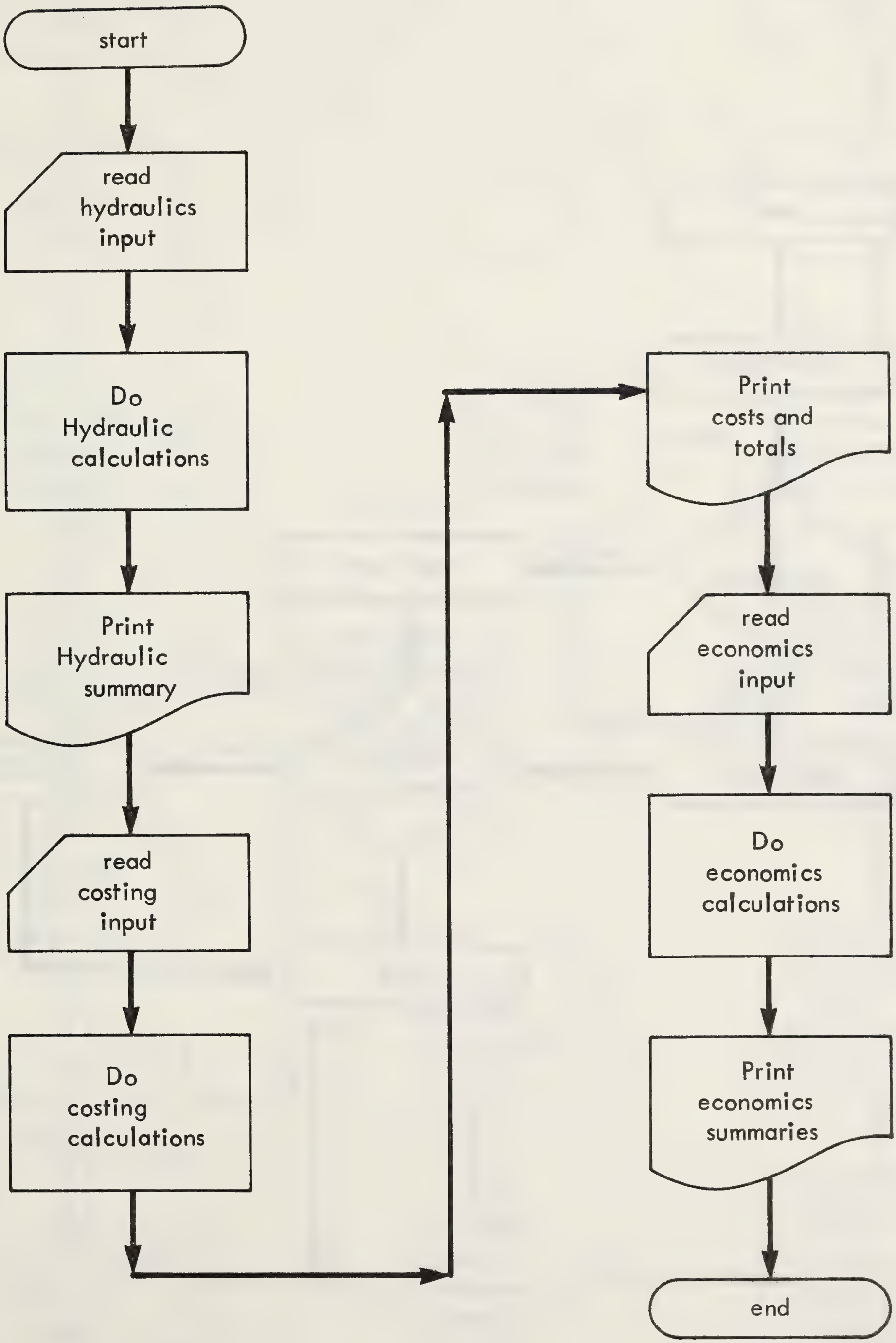
In order to carry out a discounted cash flow rate of return analysis, an interest rate of return must be assumed and applied to the annual cash flows in order to relate them to a present value. If the present value sum of the investments equals the present value sum of the returns then the correct rate of return was initially assumed. If the present values are not equal then another interest rate of return must be chosen and the calculations repeated. This iterative trial and error process is continued until the present values are equal. The resulting interest rate is defined as the discounted cash flow rate of return for the project. The program begins the calculations with an assumed 10 percent interest rate of return and proceeds with the trial and error calculations until the true rate of return is found.

A year by year summary of revenues, expenses, depreciation, taxes, profit and cash flow is printed out along with the discounted cash flow rate of return corresponding to the tariffs that were input to the program. The program then requires a new suggested tariff for further analysis. This allows the program user to examine the rate of return as a function of the tariff charged. It also lets the user seek the tariff which will allow the project to earn whatever rate of return is deemed desirable. Inputting (-1) as the commodity tariff will return the user to the mainline program.

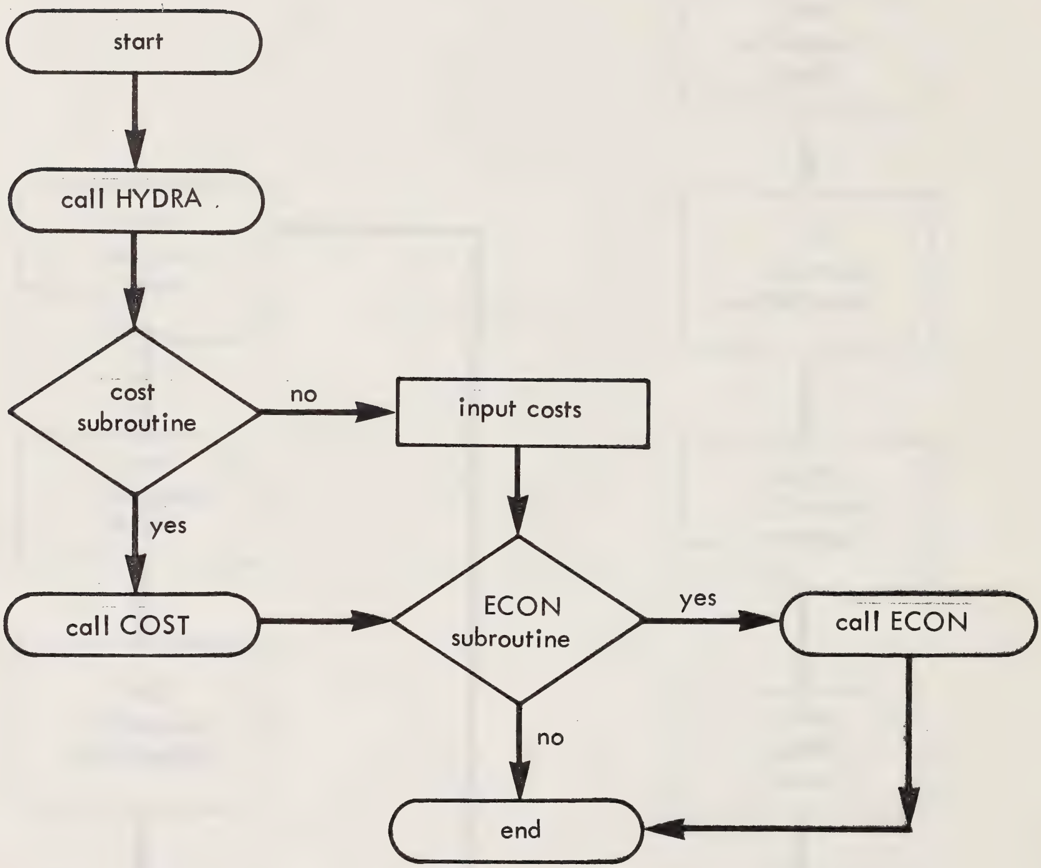
APPENDIX A – Computer Flowcharts

1. General flowchart
2. Main flowchart
3. Hydraulic flowchart (HYDRA)
4. Costing flowchart (COST)
5. Economics flowchart (ECON)

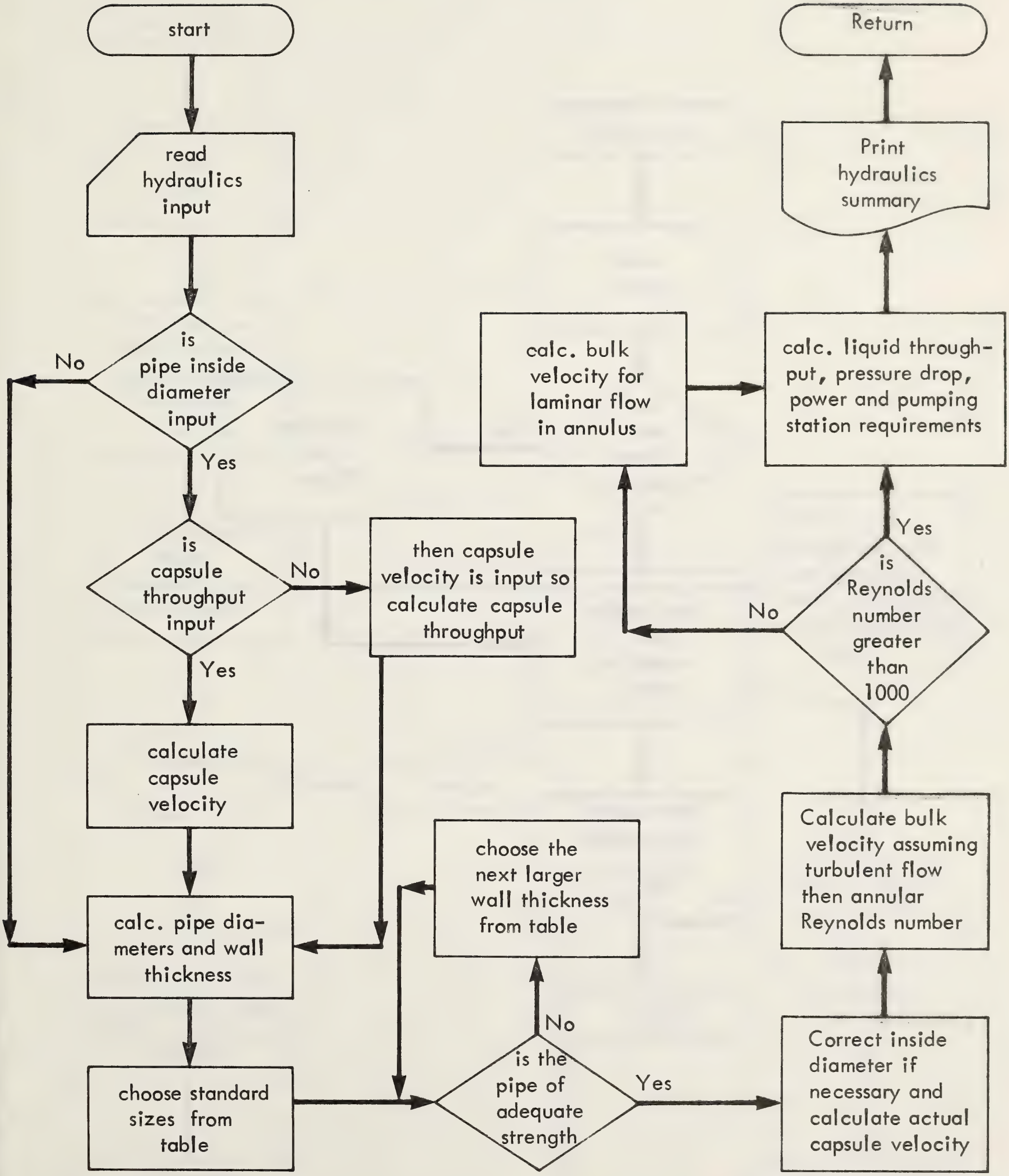
GENERAL FLOWCHART



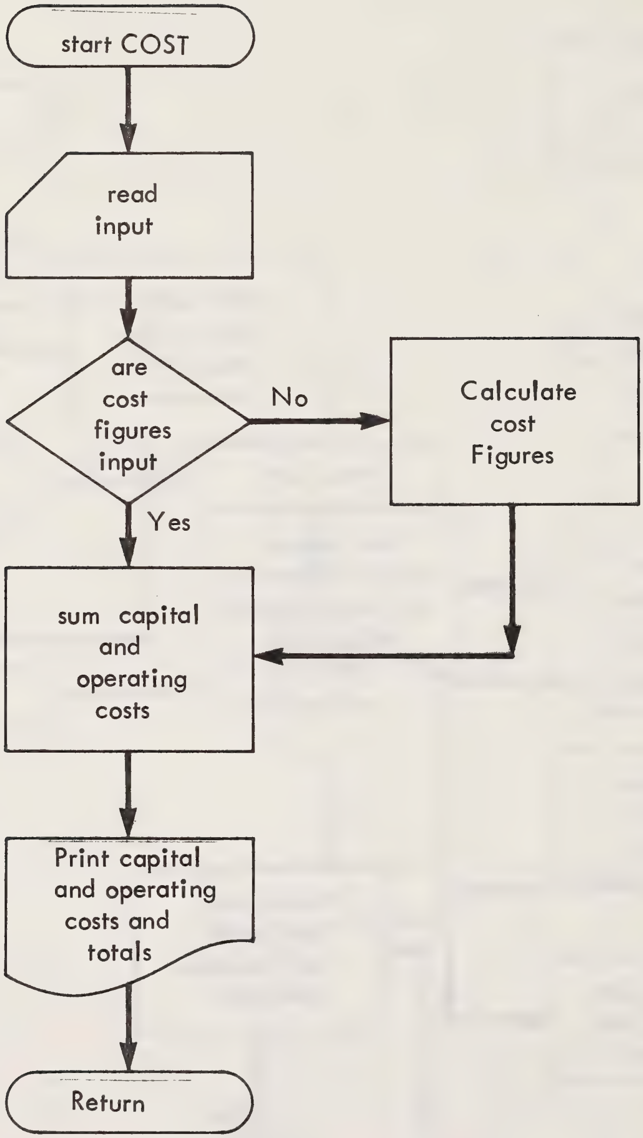
MAIN FLOWCHART



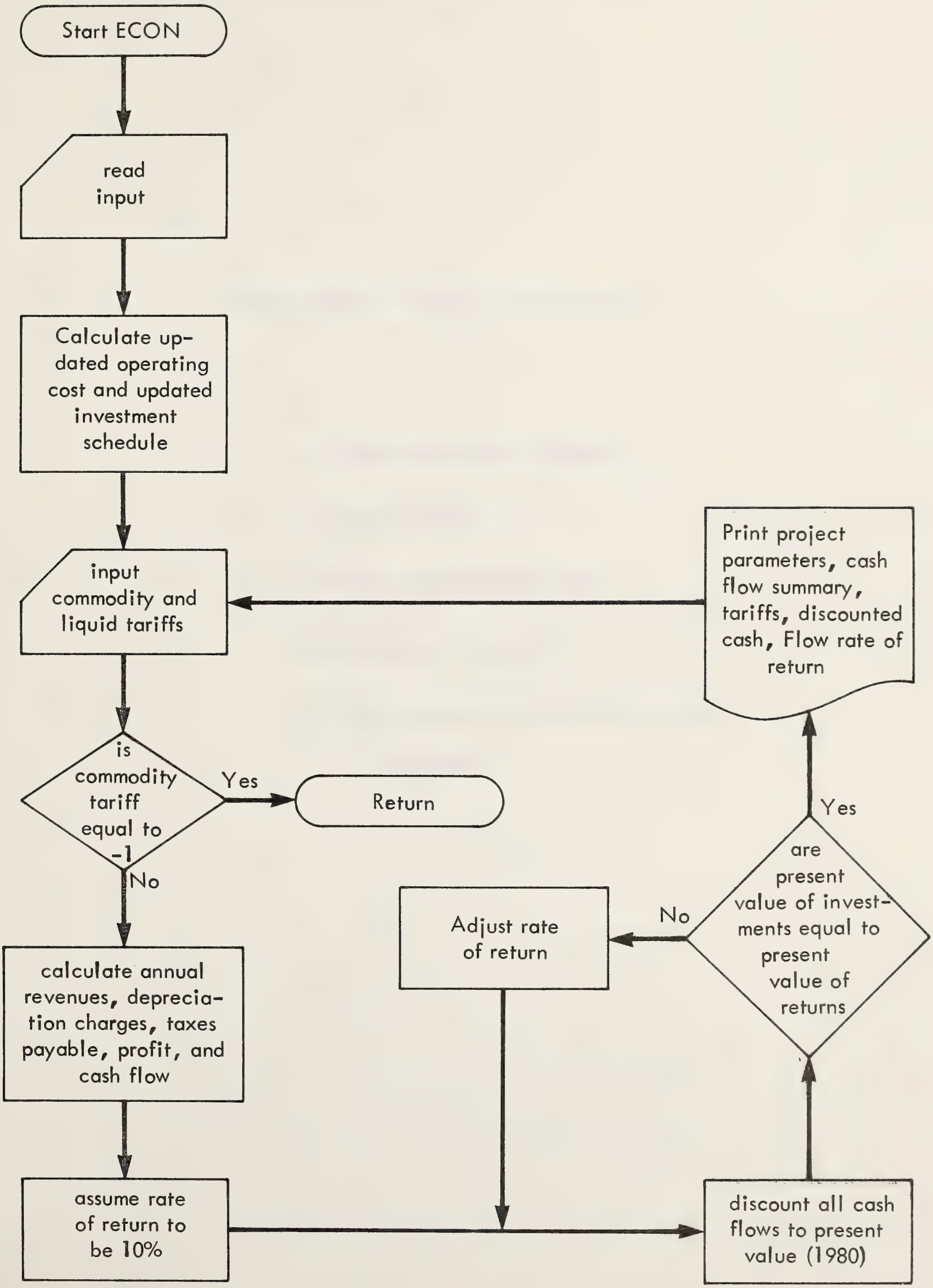
HYDRAULIC FLOWCHART



COSTING FLOWCHART



ECONOMICS FLOWCHART



APPENDIX B - Program and Data Banks

1. Nomenclature used in program
2. Program listing
3. Table of standard pipe sizes
4. Coding used in program
5. Values presently included in the costing subroutine.

Nomenclature as used in the computer program (in order of occurrence):

OR	Place of pipeline origin
DES	Place of pipeline destination
COMM	Commodity transported
CAR	Carrier liquid used
L	Pipeline length (miles)
Y	Pipeline elevation change (ft.)
WC	Commodity throughput (MMTPY)
VC	Capsule velocity (MMTPY)
DR	Ratio of capsule diameter to inside pipe diameter
F	Fractional linear fill of capsules
S	Minimum yield strength of pipe steel used (psi)
P	Maximum allowable working pressure for the system (psi)
PGC	Capsule pressure gradient (psi/mile)
RO	Liquid specific gravity
SIGC	Commodity specific gravity
VIS	Kinematic viscosity of the carrier liquid at the operating temperature (ft^2/sec)
CC	Capsule code: 1 for spheres, 0 for cylinders
TW	Wall coating thickness (in.)
TE	End cap thickness (in.)
SIGE	Specific gravity of capsule end plate
SIGW	Specific gravity of capsule wall coating material
PS	Pump suction pressure (psi)
T	Pipe wall thickness (in.)
DO	Pipe outside diameter (in.)
VB	Bulk velocity (ft./sec.)
RE	Reynolds number in annulus between capsule and pipe wall
PGF	Liquid pressure gradient (psi/mile)
PGY	Pressure gradient due to elevation change (psi/mile)

Nomenclature - continued

TPG	Total pressure gradient (psi/mile)
NPS	Number of pumping stations
SS	Pumping station spacing (miles)
IHPPS	Installed horsepower per station
IHP	Installed horsepower
WL	Carrier liquid throughput (MMTPY)
CL	Carrier liquid cost ($/1000 Imp. gal.)
FR	Liquid flowrate (USGPM)
GF	Geographic Factor
TC	Total capital cost ($/1000)
TO	Total operating cost per year ($/1000)
POC	Pipeline origin capital cost ($/1000)
POO	Pipeline origin operating cost ($/1000)
PC	Pipeline capital cost ($/1000)
PO	Pipeline operating cost ($/1000)
PBC	Pump and bypass station capital cost ($/1000)
PBO	Pump and bypass station operating cost ($/1000)
PTC	Pipeline terminal capital cost ($/1000)
PTO	Pipeline terminal operating cost ($/1000)
CCA	Capital cost allowance
NYC	Number of years for construction
LIFE	Expected pipeline life
TR	Corporate income tax rate
TARRC	Commodity revenue per ton of commodity
TARRL	Carrier liquid revenue per 1000 imperial gallons of liquid
TARRE	Revenue from end cap material in dollars per ton
TARRW	Revenue from wall coating material in dollars per ton
INV (i)	Investment during i-th year before startup
BV	Book value
REV (i)	Total revenue during i-th year of operation

Nomenclature - continued

DEP (i)	Depreciation charge during i-th year of operation
YLOSS (i)	Cumulative operating loss during i-th year of operation
BTP (i)	Before tax profit during i-th year of operation
TAX (i)	Income tax paid during i-th year of operation
ATP (i)	After tax profit during i-th year of operation
CF (i)	Cash flow during i-th year of operation
DCFRR	Discounted cash flow rate of return %

```
C         'WHITE SRC'
C         MAIN PROGRAM - CALLS HYDRAULICS, COSTING AND ECONOMICS
C                                 SUBROUTINES
C         I/O DEVICES AS USED
C           1    DISK
C           2    DISK
C           4    TELETYPE CONSOLE
C           5    PAPERTAPE READER
C           6    LINEPRINTER
C
C         SWITCH 9 ON   - INPUT DO & T FROM TTA
C                  OFF  - DO & T FROM 'TABL SRC'
C                10 ON  - INPUT ALL FROM PPT EXCEPT TARIFFS
C                  OFF  - 'COST' & 'ECON' INPUT FROM TTA
          LOGICAL ISENSW
          REAL L,IHP
          COMMON Z(250)
200       CALL HYDRA(L,D,T,IHP,WL,WC,RO,WE,WW)
          WRITE(4,16)
          READ(4,18) II
          IF(II.EQ.0) GO TO 106
          CALL COST(L,D,T,IHP,WL,WC,TC,TO,RO,WE,WW,COE,COW)
108       WRITE(4,17)
          READ(4,18) II
          IF(II.EQ.0) GO TO 109
          CALL ECON(TC,WC,TO,WL,RO,WE,WW,COE,COW)
109       PAUSE 12345
          GO TO 200
106       WRITE(4,15)
          READ(4,19) TO,TC,COE,COW
          GO TO 108
15        FORMAT(' INPUT COSTS - TO,TC,COE,COW - 4F13.2')
16        FORMAT(' COST SUMMARY? 1-YES  0-NO')
17        FORMAT(' CALCULATE DISC. CASH FLOW? 1-YES  0-NO')
18        FORMAT(I1)
19        FORMAT(4F13.2)
          END
```

```
      SUBROUTINE HYDRA (L,D,T,IHP,WL,WC,RO,WE,WW)
C     SUBROUTINE HYDRA - CALCULATES HYDRAULICS AND PRINTS SUMMARY
      LOGICAL ISENSW
      REAL L,IHPPS,IHP,NS,KD,KD2,KD3
      DIMENSION FN(2)
      COMMON TAB(12,18),OR(4),DES(4),COM(4),CAR(4)
      DATA FN(1),FN(2)/4HTABL,4H SRC/
      DATA F1,F2,F3,F4,FF/1H*,1H*,1H*,1H*,1H /
      DATA CODE1,CODE2,CODE3/5H CYL.,5HSPHER,5HE    /
      D=WC=VC=0.0
      F1=F2=F3=F4
      CALL SEEK(1,FN)
      DO 100 I=1,12
100   READ(1,) (TAB(I,J),J=1,18)
      READ(5,1) OR,DES,COM,CAR
      READ(5,) L,Y,WC,VC,DR,F,S,P,PGC,RO,SIGC,VIS,CC
      READ(5,) TW,TE,SIGW,SIGE,PS
      DR2=DR*DR
      IF(WC.NE.0.0) GO TO 110
      WRITE(4,14)
      READ(4,) D
110   IF((CC.EQ.0.).OR.(CC.EQ.1.)) GO TO 20
      WRITE(4,11)
19    PAUSE
20    IF(CC) 19,21,30
65    T=(1.39*P*D)/(2.*S-2.78*P)
      DO=D+2.*T
      IF(ISENSW(9)) WRITE(4,) DO,T
      IF(ISENSW(9)) GO TO 104
      DO 101 I=1,12
      IF(TAB(I,1).GT.DO) GO TO 102
101   CONTINUE
      WRITE(4,2) DO
      PAUSE
102   DO 103 J=2,18
      IF(TAB(I,J).GT.T) GO TO 104
103   CONTINUE
      WRITE(4,3)
      PAUSE
104   DO=TAB(I,1)
      T=TAB(I,J)
      IF(ISENSW(9)) READ(4,) DO,T
105   WP=2.*S*T/(1.39*DO)
      IF((.NOT.ISENSW(9)).AND.(J.GT.18)) PAUSE
      IF(WP.GE.P) GO TO 106
      IF(.NOT.ISENSW(9)) J=J+1
      IF(.NOT.ISENSW(9)) T=TAB(I,J)
      IF(ISENSW(9)) WRITE(4,) DO,T
      IF(ISENSW(9)) READ(4,) DO,T
      GO TO 105
106   D=DO-2.*T
      IF(CC) 19,13,33
151   RENP=VB*D/(12.*VIS)
      IF(RENP.LE.2000.) FL=64./RENP
      IF(RENP.GT.2000.) FL=.0056+.5*RENP**(0.-.32)
```

```
      PGF=427.*FL*RO*VB**2/D
      PGY=(62.43/144.)*Y*ROB/L
      TPG=(PGC*F+PGF*(1.-F)+PGY)
      NS=TPG*L/(P-PS)
      NNPS=NS+1.
      SS=L/NNPS
      HHPPM=(3.14159*D*D*VB/(4.*550.))*TPG
      HHPPS=HHPPM*SS
      IHPPS=HHPPS/(.75*.70)
      IHP=IHPPS*NNPS
      BPD=16310.*WL/RO
      DP=TPG*SS+PS
      FR=448.831*((3.14159*D**2)/(4.*144.))*VB
      WRITE(6,4)
      WRITE(6,5) OR,DES,COM,CAR,L,Y
      WRITE(6,6) P,S,DO,D,F1,F,DR,VC
      WRITE(6,7) WC,F3,WL,BPD
      WRITE(6,8) SIG,SIGC,SIGW,SIGE,RO,TW,WW,TE,WE
      WRITE(6,9) PGC,PGF,TPG,PS,NNPS,SS,IHPPS,FR,DP
      IF(RENP.LE.2000.) WRITE(6,10)
      RETURN
C
COMMENT  CC=0  CAPSULE IS CYLINDRICAL.
21    IF(D.EQ.0.AND.WC.NE.0.AND.VC.NE.0) GO TO 12
      IF(WC.EQ.0.AND.D.NE.0.AND.VC.NE.0) GO TO 13
      IF(VC.EQ.0.AND.D.NE.0.AND.WC.NE.0) GO TO 13
      WRITE(4,) D,WC,VC
      PAUSE
12    D=(194.2*WC/(SIGC*VC*DR2*F))**.5
      F1=FF
      GO TO 65
13    KD=DR*D
      DC=KD-2.*TW
      KD2=KD**2
      DC2=DC**2
      IF(WC.NE.0) GO TO 15
      F3=FF
      WC=.0051484*DC2*F*SIGC*VC*(1.-0.4*TE/KD)
15    IF((F1.NE.FF).AND.(F3.NE.FF)) F2=FF
      IF(ISENSW(5)) WRITE(4,) WC,DR,D,TW,TE,SIGC,F
      VC=194.2*WC*KD/(DC2*(KD-0.4*TE)*SIGC*F)
      IF(ISENSW(5)) WRITE(4,) VC
      VB1=((PGC*(D-DR*D)**1.25)/(RO*VIS**.25))**.57
      VB=DR*VC+.046*(1.-DR2)*VB1
      RE=(D*(1.-DR)*(VB-DR*VC))/(12.*(1.-DR2)*VIS)
      IF(RE.GT.1000.) GO TO 107
      VB1=(PGC*(D-DR*D)**2.)/(196000.*VIS)
      VB=DR*VC+(1.-DR2)*VB1
107   ROB=RO+F/(5.*KD*D*D)*(DC2*(5.*K)-2.*TE)*(SIGC-RO)+(2.*KD2*TE)
     1   *(SIGE-RO)+(KD2-DC2)*5.*KD*(SIGW-RO))
      TEM=20.*KD*SIGW*TW*(KD-TW)/(SIGC*DC2*(5.*KD-2.*TE))
      WL=0.0051484*ROB*VB*D*D-WC*(1.+2.*TE*SIGE/(SIGC*(5.*KD-2.*TE))
     1       +TEM)
      WW=WC*TEM*10.**6
      WE=WC*(2.*TE*SIGE/((5.*KD-2.*TE)*SIGC))*10.**6
```

```
        SIG=(0.4*DC2*TE+(KD2-DC2)*KD*SIGW+SIGC*KD*DC2)/KD**3
        COM(3)=CODE1
        GO TO 151
COMMENT  CC=1  CAPSULE IS SPHERICAL.
30      IF(D.EQ.0.AND.WC.NE.0.AND.VC.NE.0) GO TO 32
        IF(WC.EQ.0.AND.D.NE.0.AND.VC.NE.0) GO TO 33
        IF(VC.EQ.0.AND.D.NE.0.AND.WC.NE.0) GO TO 33
        WRITE(4,) D,WC,VC
        PAUSE
32      D=(291.3*WC/(SIGC*VC*DR2*F))**.5
        F1=FF
        GO TO 65
33      KD=DR*D
        DC=KD-2.*TW
        KD3=KD**3
        DC3=DC**3
        IF(WC.NE.0) GO TO 35
        F3=FF
        WC=.003432*DC3*F*SIGC*VC/KD
35      IF((F1.NE.FF).AND.(F3.NE.FF)) F2=FF
        VC=291.35*WC*KD/(DC3*SIGC*F)
        VB=VC
        ROB=RO+2.*F/(3.*KD*D*D)*(DC3*(SIGC-RO)+(KD3-DC3)*(SIGW-RO))
        TEM=(KD3-DC3)*SIGW/(DC3*SIGC)
        WL=.005148*ROB*VB*D*D-(WC*(1.+TEM))
        WW=WC*TEM*10.**6
        SIG=(DC3*SIGC+(KD3-DC3)*SIGW)/KD3
        COM(3)=CODE2
        COM(4)=CODE3
        GO TO 151
C
1       FORMAT(4A5)
2       FORMAT(' CANNOT FIND DO = ',F6.2)
3       FORMAT(' CANNOT FIND T')
4       FORMAT(1H1,20X'HYDRAULICS SUMMARY'/)
5       FORMAT(' ORIGIN:',3X4A5,'DESTINATION:',4A5/' COMMODITY:',4A5,'C
        1ARRIER:',4A5/' DISTANCE (MILES):',F10.2,3X'ELEVATION (FEET):',
        1F10.2/)
6       FORMAT(' PIPELINE'/4X'MAX. WORKING PRESSURE PERMITTED (INPUT-PS
        1I):',F10.2,'*'/4X'YIELD STRENGTH OF STEEL USED (PSI):',9XF10.2
        1,'*'/4X'OUTSIDE DIAMETER (INCHES):',18XF10.3/4X'INSIDE DIAMETE
        1R (INCHES):',19XF10.3,A1/4X'LINEAR FILL:',32XF10.2,'*'/4X'DIAM
        1ETER RATIO:',29XF10.2,'*'/4X'CAPSULE VELOCITY:',27XF10.3,A1)
7       FORMAT(' COMMODITY THROUGHPUT (MMTPY):',18XF10.2,A1/' CARRIER T
        1HROUGHPUT (MMTPY):',20XF10.2/20X'(BPD):',22XF10.2/)
8       FORMAT(' CAPSULE SPECIFIC GRAVITY:',22XF10.3/' COMMODITY SPECIF
        1IC GRAVITY:',20XF10.3,'*'/' WALL MATERIAL SPECIFIC GRAVITY:',1
        16XF10.3,'*'/' END PLATE MATERIAL SPECIFIC GRAVITY:',11XF10.3,'
        1*'/' LIQUID SPECIFIC GRAVITY:',23XF10.3,'*'/' WALL THICKNESS O
        1F PROTECTIVE COATING (INCHES):',F11.3,'*'/' ANNUAL THROUGHPUT
        1OF WALL MATERIAL (TPY):',3XF13.3,/' END CAP THICKNESS OF PROT.
        1 COATING (INCHES):',3XF10.3/' ANNUAL THROUGHPUT OF END CAP MAT
        1ERIAL (TPY):',3XF10.3/)
9       FORMAT(' CAPSULE PRESSURE GRADIENT (PSI/MI):',12XF10.3,'*'/' LI
        1QUID PRESSURE GRADIENT (PSI/MI):',13XF10.3/' TOTAL PRESS. GRAD
```

```
     1. (PSI/MI):',19XF10.3/' PRESSURE AT THE PUMP SUCTION:',18XF10.
     13,'*'/' REQUIRED NUMBER OF STATIONS:',21XI8/' STATION SPACING
     1(MILES):',23XF10.2/' INSTALLED H.P./STATION AT .525 EFFICIENCY
     1:',5XF10.2/' PUMP RATING:',6XF10.2,' USGPM AT',6XF10.2,' PSI')
10   FORMAT(' NOTE:  LAMINAR FLOW')
11   FORMAT(' CAPSULE CODE INCORRECT - NOT 1 OR 0.')
14   FORMAT(' INPUT D - DIAMETER')
     END
```

```
      SUBROUTINE COST (L,D,T,IHP,WL,WC,TC,TO,RO,WE,WW,COE,COW)
C     PRINTS COST SUMMARY
      LOGICAL ISENSW
      INTEGER COMM,OPT
      REAL L,IHP
      DIMENSION FILE(2)
      COMMON A1(9,4,2),A2(9,4,2)
      DATA FILE(1),FILE(2)/5HARRAY,4H SRC/
      CALL SEEK(2,FILE)
      DO 200 K=1,2
200   READ(2,12) ((A1(I,J,K),J=1,4),I=1,9)
      DO 201 K=1,2
201   READ(2,12) ((A2(I,J,K),J=1,4),I=1,9)
      IF(ISENSW(10)) READ(5,) COMM,MODE,OPT,CL,GF,CW,CE
      IF(ISENSW(10)) GO TO 204
      WRITE(4,14)
      READ(4,) COMM,MODE,OPT,CL,GF,CW,CE
204   COE=WE*CE/1000.
      COW=WW*CW/1000.
      I=COMM
      K=MODE
      IF(OPT.EQ.0) GO TO 202
      POKC=A1(I,1,K)
      POEC=A1(I,2,K)
      POKO=A1(I,3,K)
      POEO=A1(I,4,K)
      PTKC=A2(I,1,K)
      PTEC=A2(I,2,K)
      PTKO=A2(I,3,K)
      PTEO=A2(I,4,K)
      POC=POKC*WC**POEC
      POO=POKO*WC**POEO+200.*CL*WL/RO+COE+COW
      PC=L*(36.13+14.45*T*(D+T))*GF
      PO=.011*PC
      PBC=.58*IHP
      PBO=.153*IHP
      PTC=196.*WL**.27+PTKC*WC**PTEC
      PTO=29.3*WL**.35+PTKO*WC**PTEO
      GO TO 203
202   IF(ISENSW(10)) READ(5,) POC,POO,PC,PO,PBC,PBO,PTC,PTO
      IF(ISENSW(10)) GO TO 203
      WRITE(4,15)
      READ(4,) POC,POO,PC,PO,PBC,PBO,PTC,PTO
203   TC=POC+PC+PBC+PTC
      TO=POO+PO+PBO+PTO
      WRITE(6,13)
      WRITE(6,11) POC,POO,PC,PO,PBC,PBO,PTC,PTO,TC,TO
11    FORMAT(' PIPELINE ORIGIN',F14.3,7XF10.3/' PIPELINE',8XF13.3,7XF
     110.3/' PUMP & BY-PASS',2X,F13.3,7XF10.3/' PIPELINF TERMINAL'
     1,F12.3,7XF10.3/'     TOTAL ',7XF13.3,7XF10.3)
12    FORMAT(4F5.0)
13    FORMAT(//////////18X' CAPSULE PIPELINE COST SUMMARY  ($ 1973)'/
     1/20X'INVESTMENT      ANNUAL EXPENSE'/22X'($000)',11X'($000)'//)
14    FORMAT(' INPUT COMMODITY, MODE, OPTION, CL,GF,CW,CE')
15    FORMAT(' INPUT POC,POO,PC,PO,PBC,PBO,PTC,PTO')
```

```
TC=TC*1000.
TO=TO*1000.
COE=COE*1000.
COW=COW*1000.
RETURN
END
```

```
      SUBROUTINE ECON (TC,WC,TO,WL,RO,WE,WW,COE,COW)
C     CALCULATES DISCOUNTED CASH FLOW RATE OF RETURN
      LOGICAL ISENSW
      REAL INV
      COMMON CF(30),INV(30),REV(30),DEP(30),BTP(30),TAX(30),ATP(30),
     6YLOSS(30)
      IF(ISENSW(10)) READ(5,) CCA,NYC,LIFE,TR
      IF(ISENSW(10)) GO TO 200
      WRITE(4,18)
      READ(4,) CCA,NYC,LIFE,TR
200   TO=TO*1.714
      TO1=TO-0.5*(COE+COW)*1.714
      YINV=TC/NYC
      BV=0.
      DO 10 I=1,NYC
      INV(I)=YINV*1.587/(1.08**(I-1))
10    BV=BV+INV(I)
      INV(1)=INV(1)+TO1/4.
      BVD=BV/1000000.
      LIFE1=LIFE-1
      DO 30 I=1,LIFE1
      DEP(I)=CCA*BV
30    BV=BV-DEP(I)
      DEP(LIFE)=BV+TO/4.
160   WRITE(4,15)
      READ(4,) TARRC,TARRL,TARRE,TARRW
      IF(TARRC.EQ.(-1.)) GO TO 170
      TARRE=1.714*TARRE
      TARRW=1.714*TARRW
      TARRC=1.714*TARRC
      TARRL=1.714*TARRL
      REV(1)=TARRC*0.5*WC*1000000.+TARRL*.5*WL*200000./RO
     1         +TARRE*.5*WE+TARRW*.5*WW
      DO 20 I=2,LIFE
20    REV(I)=TARRC*WC*1000000.+TARRL*WL*200000./RO+TARRE*WE+TARRW*WW
      DO 40 I=1,LIFE
      BTP(I)=REV(I)-DEP(I)-TO-YLOSSC
      IF(I.EQ.1) BTP(1)=REV(1)-DEP(1)-TO1
      IF(BTP(I).LT.0.) GO TO 31
      TAX(I)=TR*BTP(I)
      ATP(I)=BTP(I)-TAX(I)
      CF(I)=REV(I)-TO-TAX(I)
      IF(I.EQ.1) CF(1)=REV(1)-TO1-TAX(1)
      YLOSS(I)=YLOSSC=0.
      GO TO 40
31    CF(I)=REV(I)-TO
      IF(I.EQ.1) CF(1)=REV(1)-TO1
      YLOSSC=YLOSS(I)=-BTP(I)
40    CONTINUE
      VAL=0.01
      IFLAG=0
      DCFRR=0.1
150   SUMI=0.
      DO 50 I=1,NYC
```

```
50       SUMI=SUMI+INV(I)*(1.0+DCFRR)**(I-1)
         SUMC=0.
         DO 60 I=1,LIFE
60       SUMC=SUMC+CF(I)/(1.0+DCFRR)**I
         RES=SUMI-SUMC
         IF(RES.GT.0.) GO TO 110
         KFLAG=1
         IF(KFLAG.EQ.IFLAG) GO TO 130
         VAL=VAL/2.
130      IFLAG=1
         DCFRR=DCFRR+VAL
         GO TO 140
110      KFLAG=-1
         IF(KFLAG.EQ.IFLAG) GO TO 120
         VAL=VAL/2.
120      IFLAG=-1
         DCFRR=DCFRR-VAL
         IF(DCFRR.LT.0.) GO TO 99
140      IF(VAL.LT..0001) GO TO 99
         GO TO 150
99       CONTINUE
         TOD=TO/1000000.
         WRITE(6,500)
         WRITE(6,501) BVD,NYC,CCA,TOD,TR,LIFE
         WRITE(6,507)
         DO 145 I=1,LIFE
         REVD=REV(I)/1000000.
         TOD=TO/1000000.
         IF(I.EQ.1) TOD=TO1/1000000.
         DEPD=DEP(I)/1000000.
         YLOSSD=YLOSS(I)/1000000.
         TAXD=TAX(I)/1000000.
         ATPD=ATP(I)/1000000.
         CFD=CF(I)/1000000.
         WRITE(6,508) I,REVD,TOD,DEPD,YLOSSD,TAXD,ATPD,CFD
145      CONTINUE
         WRITE(6,509) TARRC,TARRL,TARRE,TARRW
         IF(DCFRR.LT.0.) WRITE(6,512)
         IF(DCFRR.GE.0.) DCFRRM=DCFRR*100.
         IF(DCFRR.GE.0.) WRITE(6,511) DCFRRM
         WRITE(6,515)
         GO TO 160
15       FORMAT(' INPUT TARIFF: -1 WILL RETURN YOU TO MAIN PROGRAM')
18       FORMAT(' INPUT CAP. COST,YRS. TO CONST.,PROJECT LIFE,TAX RATE')
500      FORMAT('1',20X'DISCOUNTED CASH FLOW SUMMARY  ($MM)')
501      FORMAT(//12X' FIXED CAPITAL INVESTMENT  ($MM)',9XF10.2/13X'NUMB
         1ER OF YEARS OF CONSTRUCTION',16XI3,'*'/13X'ANNUAL CAPITAL COST
         1 ALLOWANCE',11XF10.2,'*'/13X'ANNUAL OPERATING EXPENSE  ($MM)',
         19XF10.2/13X'INCOME TAX RATE',25XF10.2,'*'/13X'PROJECT LIFE',35
         1XI3,'*'/13X'FIRST YEAR OF OPERATION',23X'1980')
507      FORMAT(///' YEAR   REVENUE OPERATING   DEPREC.      LOSS',7X'TA
         1X',7X'NET',6X'CASH'/21X'COST',12X'(IF ANY)   PAYABLE',4X'PROFI
         1T',6X'FLOW'/)
508      FORMAT(' ',I4,7F10.2)
509      FORMAT(' ',//9X'1980 TARIFFS'/13X'COMMODITY ($/TON)',30XF10.2/
```

```
     113X'LIQUID ($/1000 IG)',29XF10.2/13X'ENCAPSULATION MATERIAL (
     1$/TON)'/17X'END CAP',36XF10.2/17X'WALL MATERIAL',30XF10.2)
511  FORMAT(9X'DISCOUNTED CASH FLOW RATE OF RETURN (PERCENT)',F16.2)
512  FORMAT(9X'DISCOUNTED CASH FLOW RATE OF RETURN IS NEGATIVE')
515  FORMAT(///////////' *  INDICATES VALUE INPUT')
170  RETURN
     END
```

TABLE OF STANDARD

PIPE SIZES

Outside Diameter (in.)	Wall Thickness (in.)
4.50	0.125
	0.141
	0.156
	0.172
	0.188
	0.203
	0.219
	0.237
	0.250
	0.281
	0.312
	0.337
	0.438
	0.531
	0.674
6.625	0.125
	0.141
	0.156
	0.172
	0.188
	0.203
	0.219
	0.250
	0.280
	0.312
	0.344
	0.375
	0.432
	0.500
	0.562
	0.625
	0.719

Outside Diameter (in.)	Wall Thickness (in.)
8.625	0.188
	0.203
	0.219
	0.250
	0.277
	0.312
	0.322
	0.344
	0.375
	0.438
	0.500
	0.562
	0.625
	0.719
10.75	0.188
	0.203
	0.219
	0.250
	0.279
	0.307
	0.344
	0.365
	0.438
	0.500
	0.562
	0.625
	0.719
12.75	0.188
	0.203
	0.219
	0.250
	0.281
	0.312
	0.330
	0.344
	0.375
	0.406
	0.438
	0.500
	0.562
	0.625
	0.688
	0.750

Outside Diameter (in.)	Wall Thickness (in.)
14	0.210
	0.219
	0.250
	0.281
	0.312
	0.344
	0.375
	0.406
	0.438
	0.469
	0.500
	0.562
	0.625
	0.688
	0.750
16	0.203
	0.219
	0.250
	0.281
	0.312
	0.344
	0.375
	0.406
	0.438
	0.469
	0.500
	0.562
	0.625
	0.688
	0.750

Outside Diameter (in.)	Wall Thickness (in.)
	0.219
	0.250
	0.281
	0.312
	0.344
	0.375
	0.406
18	0.438
	0.469
	0.500
	0.562
	0.625
	0.688
	0.750
	0.812
	0.219
	0.250
	0.281
	0.312
	0.344
	0.375
	0.406
20	0.438
	0.469
	0.500
	0.562
	0.625
	0.688
	0.750
	0.812
	0.219
	0.250
	0.281
	0.312
	0.344
	0.375
	0.406
22	0.438
	0.469
	0.500
	0.562
	0.625
	0.688
	0.750
	0.812
	0.250
	0.281
	0.312
	0.344
	0.375
	0.406
24	0.438
	0.469
	0.500
	0.562
	0.625
	0.683
	0.750
	0.812
	0.250
	0.281
	0.312
	0.344
	0.375
	0.406
	0.438
26	0.469
	0.500
	0.562
	0.625
	0.638
	0.750

CODING USED IN HYDRODYNAMICS INPUT

CC

1	If the capsules are spheres
2	If the capsules are cylinders

CODING USED IN COSTING INPUT

COMM

1	For potash capsules in oil
2	For potash capsules in water
3	For sulphur capsules in oil
4	For sulphur capsules in water
5	For coal capsules in oil
6	For coal capsules in water
7	For iron ore capsules in oil
8	For iron ore capsules in water
9	For solid waste in water

MODE

1	For no protective coating on capsules
2	For non-returnable plastic container
3	For non-returnable metal container
4	For returnable container or coating.

OPT

0	If capital and operating expenses are to be input
1	If capital and operating expenses are to be calculated

VALUES PRESENTLY INCLUDED IN COSTING SUBROUTINE

Pipeline Origin

MODE	COMM	POKC	POEC	POKO	POEO
1	3	5335	.54	936	.59
	4	5335	.54	936	.59
	5	3940	.49	816	.49
	7	2715	.56	869	.68
	8	2715	.56	869	.68
	9	3664	.50	550	.60
2	1	3743	.72	560	.64
	2	3743	.72	560	.64
	3	5600	.54	1050	.47
	4	5600	.54	1050	.47
	9	4211	.60	632	.60

POC = (POKC * WC * POEC)
POO = (POKO * WC * POEO) + (200 * CL * WL/RO)
POO = POO + CM if Mode 2 or 3

Pipeline Terminal

MODE	COMM	PTKC	PTEC	PTKO	PTEO
1	5	990	.61	630	.90
	7	390	.69	76	.33
	8	330	.69	73	.33
	9	165	.60	36	.60
2	1	480	.81	56	.75
	2	410	.86	54	.74
	3	589	.57	91	.78
	4	510	.60	89	.78
	9	185	.60	40	.60

PTC = (196 * WL ** .27) + (PTKC * WC ** PTEC)
PTO = (29.3 * WL ** .35) + (PTKO * WC ** PTEO)

APPENDIX C – Sample Problems

Computer input and printout

APPENDIX C

Computated Examples:

Consider the possibility of transporting sulfur via a capsule pipeline from Calgary to Vancouver using water as the carrier liquid. Assume a steady demand of 2 million tons per year. A route, 560 miles long with an elevation decrease of 3500 feet, is designated.

Assume further that for integrity and strength reasons the capsules have to be plastic coated, that the plastic coating costs 35¢/lb. ($700/ton) and 80% of this cost ($560/ton) is recovered through sale of the plastic at the terminal. That is, there will be a plastic cost to the pipeline due to attrition and possibly due to lowering the grade of the plastic, plus a transportation credit resulting in a net cost of $140/ton of plastic encapsulation material. Assume also that the minimum operating temperature is 35°F and that water costs 10¢ per thousand imperial gallons.

At least 4 possibilities exist:

1. Molten sulfur is cast into cylindrical capsules of specific gravity 1.9, and coated with 10 mil of plastic.
2. Foamed sulfur is cast into cylindrical capsules of specific gravity 1.1 and coated with 10 mil of plastic.
3. 20 mil thick plastic bags are filled with powdered sulfur of 1.4 specific gravity.
4. Molten sulfur is cast into spherical capsules of specific gravity 1.9 and coated with 10 mil of plastic.

Common data used in all 4 cases:

L = 560 mi.	P = 1400 psi
Y = 3500 ft.	PS = 100 psi
WC = 2 MMTPY	RO = 1
VC = 6 ft./sec.	VIS = .000019 $ft.^2/sec.$
DR = .89	CL = $ .10
F = .80	GF = 1.3
S = 46000 psi	SIGE = SIGW = 0.95

General Comments

1. Capsule pressure gradients for cases 1, 2 and 3 were interpolated from Figure 39, Chapter 3 of the TDA-RCA Capsule Pipeline Project Phase 3 Report, which actually applies to Polyken tape covered cylindrical capsules in a 10 inch Schedule 40 steel pipeline, and for case 4 was interpolated from Figures 85 and 87 of Chapter 3 of the same report.

2. The diameter ratio chosen (.89) may be a little large in practice for cylinders but has been used because it is one for which data are readily available.

3. A geographic factor of 1.3 was used to allow for extra cost of building a pipeline through partly mountainous terrain.

4. All cases were run at two commodity tariff rates, \$9 and \$12 per ton in 1973 dollars.

```
Calgary
 Vancouver
  Sulfur
  Water
562 -3500 2 6 .89 .8 42000 1400 224 1 1.9 .000019 0
.01 .01 .95 .95 100
1
4 2 1 .1 1.3 700 700
1
.09 3 25 .5
9 0 560 560
12 0 560 560
-1 0 0 0
```

```
Calgary
 Vancouver
  Sulfur
  Water
562 -3500 2 6 .89 .8 42000 1400 42 1 1.1 .000019 0
.01 .01 .95 .95 100
1
4 2 1 .1 1.3 700 700
1
.09 3 25 .5
9 0 560 560
12 0 560 560
-1 0 0 0
```

```
Calgary
 Vancouver
  Sulfur
  Water
562 -3500 2 6 .89 .8 42000 1400 120 1 1.4 .000019 0
.01 .02 .95 .95 100
1
2 2 1 .1 1.3 700 700
1
.09 3 25 .5
9 0 560 560
12 0 560 560
```

```
Calgary
 Vancouver
  Sulfur
  Water
562 -3500 2 6 .89 .8 42000 1400 38 1 1.9 .000019 1
.01 .00 .95 .00 100
1
4 2 1 .1 1.3 700 00
1
.09 3 25 .5
9 0 560 560
12 0 560 560
-1 0 0 0
```

<u>Case 1 - cast cylindrical capsules:</u>

SIG = 1.9 (specific gravity of capsule)

PGC = 224 psi/mile

CC = 0 (capsule code to indicate cylinder)

COMM = 4 (i.e. sulfur in water)

MODE = 2 (i.e. non-returnable plastic coating)

CE = CW = $700

TE = TW = 0.010 inches

TARRE = TARRW = $560

Note: Equation 9 of TDA-RCA Phase 3 Report, Chapter 5 was used in conjunction with Figure 39 of Chapter 3 to arrive at the capsule pressure gradient for this high capsule specific gravity case.

HYDRAULICS SUMMARY

ORIGIN: Calgary DESTINATION: Vancouver
COMMODITY: Sulfur CYL. CARRIER: Water
DISTANCE (MILES): 562.00 ELEVATION (FEET): -3500.00

PIPELINE	
MAX. WORKING PRESSURE PERMITTED (INPUT-PSI):	1400.00*
YIELD STRENGTH OF STEEL USED (PSI):	42000.00*
OUTSIDE DIAMETER (INCHES):	8.625
INSIDE DIAMETER (INCHES):	8.219
LINEAR FILL:	0.80*
DIAMETER RATIO:	0.89*
CAPSULE VELOCITY:	4.804
COMMODITY THROUGHPUT (MMTPY):	2.00*
CARRIER THROUGHPUT (MMTPY):	0.82
(BPD):	13419.70
CAPSULE SPECIFIC GRAVITY:	1.895
COMMODITY SPECIFIC GRAVITY:	1.900*
WALL MATERIAL SPECIFIC GRAVITY:	0.950*
END PLATE MATERIAL SPECIFIC GRAVITY:	0.950*
LIQUID SPECIFIC GRAVITY:	1.000*
WALL THICKNESS OF PROTECTIVE COATING (INCHES):	0.010*
ANNUAL THROUGHPUT OF WALL MATERIAL (TPY):	5493.796
END CAP THICKNESS OF PROT. COATING (INCHES):	0.010
ANNUAL THROUGHPUT OF END CAP MATERIAL (TPY):	547.128
CAPSULE PRESSURE GRADIENT (PSI/MI):	224.000*
LIQUID PRESSURE GRADIENT (PSI/MI):	22.233
TOTAL PRESS. GRAD. (PSI/MI):	179.417
PRESSURE AT THE PUMP SUCTION:	100.000*
REQUIRED NUMBER OF STATIONS:	78
STATION SPACING (MILES):	7.21
INSTALLED H.P./STATION AT .525 EFFICIENCY:	1233.17
PUMP RATING: 858.54 USGPM AT	1392.72 PSI

CAPSULE PIPELINE COST SUMMARY ($ 1973)

	INVESTMENT ($000)	ANNUAL EXPENSE ($000)
PIPELINE ORIGIN	8142.246	5699.467
PIPELINE	44445.812	488.904
PUMP & BY-PASS	55788.413	14716.599
PIPELINE TERMINAL	958.960	180.191
TOTAL	109335.434	21085.161

DISCOUNTED CASH FLOW SUMMARY ($MM)

FIXED CAPITAL INVESTMENT ($MM)	160.98
NUMBER OF YEARS OF CONSTRUCTION	3*
ANNUAL CAPITAL COST ALLOWANCE	0.09*
ANNUAL OPERATING EXPENSE ($MM)	36.14
INCOME TAX RATE	0.50*
PROJECT LIFE	25*
FIRST YEAR OF OPERATION	1980

YEAR	REVENUE	OPERATING COST	DEPREC.	LOSS (IF ANY)	TAX PAYABLE	NET PROFIT	CASH FLOW
1	18.33	32.52	14.49	28.68	0.00	0.00	-14.19
2	36.65	36.14	13.18	41.35	0.00	0.00	0.51
3	36.65	36.14	12.00	52.84	0.00	0.00	0.51
4	36.65	36.14	10.92	63.25	0.00	0.00	0.51
5	36.65	36.14	9.94	72.67	0.00	0.00	0.51
6	36.65	36.14	9.04	81.20	0.00	0.00	0.51
7	36.65	36.14	8.23	88.92	0.00	0.00	0.51
8	36.65	36.14	7.49	95.90	0.00	0.00	0.51
9	36.65	36.14	6.81	102.20	0.00	0.00	0.51
10	36.65	36.14	6.20	107.89	0.00	0.00	0.51
11	36.65	36.14	5.64	113.02	0.00	0.00	0.51
12	36.65	36.14	5.13	117.64	0.00	0.00	0.51
13	36.65	36.14	4.67	121.81	0.00	0.00	0.51
14	36.65	36.14	4.25	125.55	0.00	0.00	0.51
15	36.65	36.14	3.87	128.91	0.00	0.00	0.51
16	36.65	36.14	3.52	131.92	0.00	0.00	0.51
17	36.65	36.14	3.20	134.61	0.00	0.00	0.51
18	36.65	36.14	2.92	137.02	0.00	0.00	0.51
19	36.65	36.14	2.65	139.16	0.00	0.00	0.51
20	36.65	36.14	2.41	141.06	0.00	0.00	0.51
21	36.65	36.14	2.20	142.75	0.00	0.00	0.51
22	36.65	36.14	2.00	144.24	0.00	0.00	0.51
23	36.65	36.14	1.82	145.55	0.00	0.00	0.51
24	36.65	36.14	1.66	146.69	0.00	0.00	0.51
25	36.65	36.14	25.78	171.96	0.00	0.00	0.51

1980 TARIFFS	
COMMODITY ($/TON)	15.43
LIQUID ($/1000 IG)	0.00
ENCAPSULATION MATERIAL ($/TON)	
END CAP	959.84
WALL MATERIAL	959.84

DISCOUNTED CASH FLOW RATE OF RETURN IS NEGATIVE

* INDICATES VALUE INPUT

DISCOUNTED CASH FLOW SUMMARY ($MM)

FIXED CAPITAL INVESTMENT ($MM)	160.98
NUMBER OF YEARS OF CONSTRUCTION	3*
ANNUAL CAPITAL COST ALLOWANCE	0.09*
ANNUAL OPERATING EXPENSE ($MM)	36.14
INCOME TAX RATE	0.50*
PROJECT LIFE	25*
FIRST YEAR OF OPERATION	1980

YEAR	REVENUE	OPERATING COST	DEPREC.	LOSS (IF ANY)	TAX PAYABLE	NET PROFIT	CASH FLOW
1	23.47	32.52	14.49	23.54	0.00	0.00	-9.05
2	46.93	36.14	13.18	25.93	0.00	0.00	10.79
3	46.93	36.14	12.00	27.13	0.00	0.00	10.79
4	46.93	36.14	10.92	27.25	0.00	0.00	10.79
5	46.93	36.14	9.94	26.39	0.00	0.00	10.79
6	46.93	36.14	9.04	24.64	0.00	0.00	10.79
7	46.93	36.14	8.23	22.07	0.00	0.00	10.79
8	46.93	36.14	7.49	18.77	0.00	0.00	10.79
9	46.93	36.14	6.81	14.79	0.00	0.00	10.79
10	46.93	36.14	6.20	10.19	0.00	0.00	10.79
11	46.93	36.14	5.64	5.04	0.00	0.00	10.79
12	46.93	36.14	5.13	0.00	0.31	0.31	10.48
13	46.93	36.14	4.67	0.00	3.06	3.06	7.73
14	46.93	36.14	4.25	0.00	3.27	3.27	7.52
15	46.93	36.14	3.87	0.00	3.46	3.46	7.33
16	46.93	36.14	3.52	0.00	3.64	3.64	7.16
17	46.93	36.14	3.20	0.00	3.80	3.80	7.00
18	46.93	36.14	2.92	0.00	3.94	3.94	6.85
19	46.93	36.14	2.65	0.00	4.07	4.07	6.72
20	46.93	36.14	2.41	0.00	4.19	4.19	6.60
21	46.93	36.14	2.20	0.00	4.30	4.30	6.50
22	46.93	36.14	2.00	0.00	4.40	4.40	6.40
23	46.93	36.14	1.82	0.00	4.49	4.49	6.31
24	46.93	36.14	1.66	0.00	4.57	4.57	6.22
25	46.93	36.14	25.78	14.98	0.00	0.00	10.79

1980 TARIFFS	
COMMODITY ($/TON)	20.57
LIQUID ($/1000 IG)	0.00
ENCAPSULATION MATERIAL ($/TON)	
END CAP	959.84
WALL MATERIAL	959.84
DISCOUNTED CASH FLOW RATE OF RETURN (PERCENT)	1.35

* INDICATES VALUE INPUT

Case 2 - cast foamed cylindrical capsules:

SIG = 1.1 (specific gravity of capsule)

PGC = 42.00 psi/mile

CC = 0 (capsule code to indicate cylinder)

COMM = 4 (i.e. sulfur in water)

MODE = 2 (i.e. non-returnable plastic coating)

CE = CW = $700

TE = TW = 0.010 inches

TARRE = TARRW = $560

HYDRAULICS SUMMARY

ORIGIN: Calgary		DESTINATION: Vancouver	
COMMODITY: Sulfur	CYL.	CARRIER: Water	
DISTANCE (MILES):	562.00	ELEVATION (FEET):	-3500.00

PIPELINE	
MAX. WORKING PRESSURE PERMITTED (INPUT-PSI):	1400.00*
YIELD STRENGTH OF STEEL USED (PSI):	42000.00*
OUTSIDE DIAMETER (INCHES):	10.750
INSIDE DIAMETER (INCHES):	10.250
LINEAR FILL:	0.80*
DIAMETER RATIO:	0.89*
CAPSULE VELOCITY:	5.329
COMMODITY THROUGHPUT (MMTPY):	2.00*
CARRIER THROUGHPUT (MMTPY):	0.96
(BPD):	15590.90
CAPSULE SPECIFIC GRAVITY:	1.100
COMMODITY SPECIFIC GRAVITY:	1.100*
WALL MATERIAL SPECIFIC GRAVITY:	0.950*
END PLATE MATERIAL SPECIFIC GRAVITY:	0.950*
LIQUID SPECIFIC GRAVITY:	1.000*
WALL THICKNESS OF PROTECTIVE COATING (INCHES):	0.010*
ANNUAL THROUGHPUT OF WALL MATERIAL (TPY):	7601.994
END CAP THICKNESS OF PROT. COATING (INCHES):	0.010
ANNUAL THROUGHPUT OF END CAP MATERIAL (TPY):	757.700
CAPSULE PRESSURE GRADIENT (PSI/MI):	42.000*
LIQUID PRESSURE GRADIENT (PSI/MI):	16.829
TOTAL PRESS. GRAD. (PSI/MI):	34.096
PRESSURE AT THE PUMP SUCTION:	100.000*
REQUIRED NUMBER OF STATIONS:	15
STATION SPACING (MILES):	37.47
INSTALLED H.P./STATION AT .525 EFFICIENCY:	1882.20
PUMP RATING: 1326.05 USGPM AT	1377.46 PSI

CAPSULE PIPELINE COST SUMMARY ($ 1973)

	INVESTMENT ($000)	ANNUAL EXPENSE ($000)
PIPELINE ORIGIN	8142.246	7325.270
PIPELINE	54109.149	595.201
PUMP & BY-PASS	16375.121	4319.644
PIPELINE TERMINAL	966.644	181.666
TOTAL	79593.162	12421.780

DISCOUNTED CASH FLOW SUMMARY ($MM)

FIXED CAPITAL INVESTMENT ($MM)	117.19
NUMBER OF YEARS OF CONSTRUCTION	3*
ANNUAL CAPITAL COST ALLOWANCE	0.09*
ANNUAL OPERATING EXPENSE ($MM)	21.29
INCOME TAX RATE	0.50*
PROJECT LIFE	25*
FIRST YEAR OF OPERATION	1980

YEAR	REVENUE	OPERATING COST	DEPREC.	LOSS (IF ANY)	TAX PAYABLE	NET PROFIT	CASH FLOW
1	19.44	16.28	10.55	7.38	0.00	0.00	3.16
2	38.88	21.29	9.60	0.00	0.30	0.30	17.28
3	38.88	21.29	8.73	0.00	4.43	4.43	13.16
4	38.88	21.29	7.95	0.00	4.82	4.82	12.77
5	38.88	21.29	7.23	0.00	5.18	5.18	12.41
6	38.88	21.29	6.58	0.00	5.50	5.50	12.08
7	38.88	21.29	5.99	0.00	5.80	5.80	11.79
8	38.88	21.29	5.45	0.00	6.07	6.07	11.52
9	38.88	21.29	4.96	0.00	6.31	6.31	11.27
10	38.88	21.29	4.51	0.00	6.54	6.54	11.05
11	38.88	21.29	4.11	0.00	6.74	6.74	10.85
12	38.88	21.29	3.74	0.00	6.92	6.92	10.66
13	38.88	21.29	3.40	0.00	7.09	7.09	10.49
14	38.88	21.29	3.10	0.00	7.24	7.24	10.34
15	38.88	21.29	2.82	0.00	7.38	7.38	10.20
16	38.88	21.29	2.56	0.00	7.51	7.51	10.07
17	38.88	21.29	2.33	0.00	7.63	7.63	9.96
18	38.88	21.29	2.12	0.00	7.73	7.73	9.85
19	38.88	21.29	1.93	0.00	7.83	7.83	9.76
20	38.88	21.29	1.76	0.00	7.91	7.91	9.67
21	38.88	21.29	1.60	0.00	7.99	7.99	9.59
22	38.88	21.29	1.46	0.00	8.06	8.06	9.52
23	38.88	21.29	1.32	0.00	8.13	8.13	9.45
24	38.88	21.29	1.21	0.00	8.19	8.19	9.40
25	38.88	21.29	17.51	0.00	0.04	0.04	17.55

1980 TARIFFS	
COMMODITY ($/TON)	15.43
LIQUID ($/1000 IG)	0.00
ENCAPSULATION MATERIAL ($/TON)	
END CAP	959.84
WALL MATERIAL	959.84
DISCOUNTED CASH FLOW RATE OF RETURN (PERCENT)	7.01

* INDICATES VALUE INPUT

DISCOUNTED CASH FLOW SUMMARY ($MM)

FIXED CAPITAL INVESTMENT ($MM)	117.19
NUMBER OF YEARS OF CONSTRUCTION	3*
ANNUAL CAPITAL COST ALLOWANCE	0.09*
ANNUAL OPERATING EXPENSE ($MM)	21.29
INCOME TAX RATE	0.50*
PROJECT LIFE	25*
FIRST YEAR OF OPERATION	1980

YEAR	REVENUE	OPERATING COST	DEPREC.	LOSS (IF ANY)	TAX PAYABLE	NET PROFIT	CASH FLOW
1	24.58	16.28	10.55	2.24	0.00	0.00	8.30
2	49.16	21.29	9.60	0.00	8.01	8.01	19.85
3	49.16	21.29	8.73	0.00	9.57	9.57	18.30
4	49.16	21.29	7.95	0.00	9.96	9.96	17.91
5	49.16	21.29	7.23	0.00	10.32	10.32	17.55
6	49.16	21.29	6.58	0.00	10.64	10.64	17.23
7	49.16	21.29	5.99	0.00	10.94	10.94	16.93
8	49.16	21.29	5.45	0.00	11.21	11.21	16.66
9	49.16	21.29	4.96	0.00	11.45	11.45	16.41
10	49.16	21.29	4.51	0.00	11.68	11.68	16.19
11	49.16	21.29	4.11	0.00	11.88	11.88	15.99
12	49.16	21.29	3.74	0.00	12.07	12.07	15.80
13	49.16	21.29	3.40	0.00	12.23	12.23	15.64
14	49.16	21.29	3.10	0.00	12.39	12.39	15.48
15	49.16	21.29	2.82	0.00	12.53	12.53	15.34
16	49.16	21.29	2.56	0.00	12.65	12.65	15.22
17	49.16	21.29	2.33	0.00	12.77	12.77	15.10
18	49.16	21.29	2.12	0.00	12.87	12.87	15.00
19	49.16	21.29	1.93	0.00	12.97	12.97	14.90
20	49.16	21.29	1.76	0.00	13.06	13.06	14.81
21	49.16	21.29	1.60	0.00	13.13	13.13	14.73
22	49.16	21.29	1.46	0.00	13.21	13.21	14.66
23	49.16	21.29	1.32	0.00	13.27	13.27	14.60
24	49.16	21.29	1.21	0.00	13.33	13.33	14.54
25	49.16	21.29	17.51	0.00	5.18	5.18	22.69

1980 TARIFFS	
COMMODITY ($/TON)	20.57
LIQUID ($/1000 IG)	0.00
ENCAPSULATION MATERIAL ($/TON)	
END CAP	959.84
WALL MATERIAL	959.84
DISCOUNTED CASH FLOW RATE OF RETURN (PERCENT)	11.12

* INDICATES VALUE INPUT

Case 3 - polyethylene filled bags of powdered sulfur:

SIG = 1.40 (specific gravity of capsule)

PGC = 120 psi/mile

CC = 0 (capsule code to indicate cylinder)

COMM = 2 (i.e. potash in water)

MODE = 2 (i.e. non-returnable plastic coating)

CE = CW = $700

TE = TW = 0.020 inches

TARRE = TARRW = $560

Note: For powdered sulfur a more substantial plastic coating is used than for the cast capsules cases.

HYDRAULICS SUMMARY

ORIGIN: Calgary   DESTINATION: Vancouver
COMMODITY: Sulfur CYL.   CARRIER: Water
DISTANCE (MILES): 562.00   ELEVATION (FEET): -3500.00

PIPELINE	
MAX. WORKING PRESSURE PERMITTED (INPUT-PSI):	1400.00*
YIELD STRENGTH OF STEEL USED (PSI):	42000.00*
OUTSIDE DIAMETER (INCHES):	10.750
INSIDE DIAMETER (INCHES):	10.250
LINEAR FILL:	0.80*
DIAMETER RATIO:	0.89*
CAPSULE VELOCITY:	4.189
COMMODITY THROUGHPUT (MMTPY):	2.00*
CARRIER THROUGHPUT (MMTPY):	1.03
(BPD):	16737.70
CAPSULE SPECIFIC GRAVITY:	1.399
COMMODITY SPECIFIC GRAVITY:	1.400*
WALL MATERIAL SPECIFIC GRAVITY:	0.950*
END PLATE MATERIAL SPECIFIC GRAVITY:	0.950*
LIQUID SPECIFIC GRAVITY:	1.000*
WALL THICKNESS OF PROTECTIVE COATING (INCHES):	0.010*
ANNUAL THROUGHPUT OF WALL MATERIAL (TPY):	5975.617
END CAP THICKNESS OF PROT. COATING (INCHES):	0.020
ANNUAL THROUGHPUT OF END CAP MATERIAL (TPY):	1191.195
CAPSULE PRESSURE GRADIENT (PSI/MI):	120.000*
LIQUID PRESSURE GRADIENT (PSI/MI):	13.072
TOTAL PRESS. GRAD. (PSI/MI):	95.234
PRESSURE AT THE PUMP SUCTION:	100.000*
REQUIRED NUMBER OF STATIONS:	42
STATION SPACING (MILES):	13.38
INSTALLED H.P./STATION AT .525 EFFICIENCY:	1631.20
PUMP RATING: 1152.05 USGPM AT	1374.32 PSI

CAPSULE PIPELINE COST SUMMARY ($ 1973)

	INVESTMENT ($000)	ANNUAL EXPENSE ($000)
PIPELINE ORIGIN	6165.403	5909.957
PIPELINE	54109.149	595.201
PUMP & BY-PASS	39736.056	10482.098
PIPELINE TERMINAL	941.540	119.756
TOTAL	100952.148	17107.012

DISCOUNTED CASH FLOW SUMMARY ($MM)

FIXED CAPITAL INVESTMENT ($MM)	148.64
NUMBER OF YEARS OF CONSTRUCTION	3*
ANNUAL CAPITAL COST ALLOWANCE	0.09*
ANNUAL OPERATING EXPENSE ($MM)	29.32
INCOME TAX RATE	0.50*
PROJECT LIFE	25*
FIRST YEAR OF OPERATION	1980

YEAR	REVENUE	OPERATING COST	DEPREC.	LOSS (IF ANY)	TAX PAYABLE	NET PROFIT	CASH FLOW
1	18.87	25.02	13.38	19.53	0.00	0.00	-6.16
2	37.73	29.32	12.17	23.30	0.00	0.00	8.41
3	37.73	29.32	11.08	25.97	0.00	0.00	8.41
4	37.73	29.32	10.08	27.64	0.00	0.00	8.41
5	37.73	29.32	9.17	28.40	0.00	0.00	8.41
6	37.73	29.32	8.35	28.34	0.00	0.00	8.41
7	37.73	29.32	7.60	27.53	0.00	0.00	8.41
8	37.73	29.32	6.91	26.03	0.00	0.00	8.41
9	37.73	29.32	6.29	23.91	0.00	0.00	8.41
10	37.73	29.32	5.72	21.23	0.00	0.00	8.41
11	37.73	29.32	5.21	18.03	0.00	0.00	8.41
12	37.73	29.32	4.74	14.36	0.00	0.00	8.41
13	37.73	29.32	4.31	10.26	0.00	0.00	8.41
14	37.73	29.32	3.93	5.78	0.00	0.00	8.41
15	37.73	29.32	3.57	0.94	0.00	0.00	8.41
16	37.73	29.32	3.25	0.00	2.11	2.11	6.30
17	37.73	29.32	2.96	0.00	2.73	2.73	5.68
18	37.73	29.32	2.69	0.00	2.86	2.86	5.55
19	37.73	29.32	2.45	0.00	2.98	2.98	5.43
20	37.73	29.32	2.23	0.00	3.09	3.09	5.32
21	37.73	29.32	2.03	0.00	3.19	3.19	5.22
22	37.73	29.32	1.85	0.00	3.28	3.28	5.13
23	37.73	29.32	1.68	0.00	3.36	3.36	5.04
24	37.73	29.32	1.53	0.00	3.44	3.44	4.97
25	37.73	29.32	22.79	14.38	0.00	0.00	8.41

1980 TARIFFS	
COMMODITY ($/TON)	15.43
LIQUID ($/1000 IG)	0.00
ENCAPSULATION MATERIAL ($/TON)	
END CAP	959.84
WALL MATERIAL	959.84
DISCOUNTED CASH FLOW RATE OF RETURN (PERCENT)	0.62

* INDICATES VALUE INPUT

DISCOUNTED CASH FLOW SUMMARY ($MM)

FIXED CAPITAL INVESTMENT ($MM)	148.64
NUMBER OF YEARS OF CONSTRUCTION	3*
ANNUAL CAPITAL COST ALLOWANCE	0.09*
ANNUAL OPERATING EXPENSE ($MM)	29.32
INCOME TAX RATE	0.50*
PROJECT LIFE	25*
FIRST YEAR OF OPERATION	1980

YEAR	REVENUE	OPERATING COST	DEPREC.	LOSS (IF ANY)	TAX PAYABLE	NET PROFIT	CASH FLOW
1	24.01	25.02	13.38	14.39	0.00	0.00	-1.01
2	48.01	29.32	12.17	7.87	0.00	0.00	18.69
3	48.01	29.32	11.08	0.26	0.00	0.00	18.69
4	48.01	29.32	10.08	0.00	4.18	4.18	14.52
5	48.01	29.32	9.17	0.00	4.76	4.76	13.93
6	48.01	29.32	8.35	0.00	5.17	5.17	13.52
7	48.01	29.32	7.60	0.00	5.55	5.55	13.15
8	48.01	29.32	6.91	0.00	5.89	5.89	12.80
9	48.01	29.32	6.29	0.00	6.20	6.20	12.49
10	48.01	29.32	5.72	0.00	6.48	6.48	12.21
11	48.01	29.32	5.21	0.00	6.74	6.74	11.95
12	48.01	29.32	4.74	0.00	6.98	6.98	11.72
13	48.01	29.32	4.31	0.00	7.19	7.19	11.50
14	48.01	29.32	3.93	0.00	7.38	7.38	11.31
15	48.01	29.32	3.57	0.00	7.56	7.56	11.13
16	48.01	29.32	3.25	0.00	7.72	7.72	10.97
17	48.01	29.32	2.96	0.00	7.87	7.87	10.83
18	48.01	29.32	2.69	0.00	8.00	8.00	10.69
19	48.01	29.32	2.45	0.00	8.12	8.12	10.57
20	48.01	29.32	2.23	0.00	8.23	8.23	10.46
21	48.01	29.32	2.03	0.00	8.33	8.33	10.36
22	48.01	29.32	1.85	0.00	8.42	8.42	10.27
23	48.01	29.32	1.68	0.00	8.51	8.51	10.19
24	48.01	29.32	1.53	0.00	8.58	8.58	10.11
25	48.01	29.32	22.79	4.09	0.00	0.00	18.69

1980 TARIFFS	
COMMODITY ($/TON)	20.57
LIQUID ($/1000 IG)	0.00
ENCAPSULATION MATERIAL ($/TON)	
END CAP	959.84
WALL MATERIAL	959.84
DISCOUNTED CASH FLOW RATE OF RETURN (PERCENT)	5.49

* INDICATES VALUE INPUT

Case 4 - cast spherical capsules:

SIG = 1.90 (specific gravity of capsule)

PGC = 38 psi/mile

CC = 1 (indicating spheres)

COMM = 4 (i.e. sulfur in water)

MODE = 2 (i.e. non-returnable plastic coating)

CW = $700

TW = 0.010 inches

TARRW = $560

HYDRAULICS SUMMARY

ORIGIN: Calgary DESTINATION: Vancouver
COMMODITY: Sulfur SPHERE CARRIER: water
DISTANCE (MILES): 562.00 ELEVATION (FEET): -3500.00

PIPELINE	
MAX. WORKING PRESSURE PERMITTED (INPUT-PSI):	1400.00*
YIELD STRENGTH OF STEEL USED (PSI):	42000.00*
OUTSIDE DIAMETER (INCHES):	10.750
INSIDE DIAMETER (INCHES):	10.250
LINEAR FILL:	0.80*
DIAMETER RATIO:	0.89*
CAPSULE VELOCITY:	4.637
COMMODITY THROUGHPUT (MMTPY):	2.00*
CARRIER THROUGHPUT (MMTPY):	1.45
(BPD):	23621.55
CAPSULE SPECIFIC GRAVITY:	1.894
COMMODITY SPECIFIC GRAVITY:	1.900*
WALL MATERIAL SPECIFIC GRAVITY:	0.950*
END PLATE MATERIAL SPECIFIC GRAVITY:	0.000*
LIQUID SPECIFIC GRAVITY:	1.000*
WALL THICKNESS OF PROTECTIVE COATING (INCHES):	0.010*
ANNUAL THROUGHPUT OF WALL MATERIAL (TPY):	6606.080
END CAP THICKNESS OF PROT. COATING (INCHES):	0.000
ANNUAL THROUGHPUT OF END CAP MATERIAL (TPY):	1191.195
CAPSULE PRESSURE GRADIENT (PSI/MI):	38.000*
LIQUID PRESSURE GRADIENT (PSI/MI):	13.909
TOTAL PRESS. GRAD. (PSI/MI):	29.462
PRESSURE AT THE PUMP SUCTION:	100.000*
REQUIRED NUMBER OF STATIONS:	13
STATION SPACING (MILES):	43.23
INSTALLED H.P./STATION AT .525 EFFICIENCY:	1687.75
PUMP RATING: 1192.59 USGPM AT	1373.68 PSI

CAPSULE PIPELINE COST SUMMARY ($ 1973)

	INVESTMENT ($000)	ANNUAL EXPENSE ($000)
PIPELINE ORIGIN	8142.246	6107.587
PIPELINE	54109.149	595.201
PUMP & BY-PASS	12725.671	3356.944
PIPELINE TERMINAL	989.630	186.180
TOTAL	75966.695	10245.912

DISCOUNTED CASH FLOW SUMMARY ($MM)

FIXED CAPITAL INVESTMENT ($MM)	111.85
NUMBER OF YEARS OF CONSTRUCTION	3*
ANNUAL CAPITAL COST ALLOWANCE	0.09*
ANNUAL OPERATING EXPENSE ($MM)	17.56
INCOME TAX RATE	0.50*
PROJECT LIFE	25*
FIRST YEAR OF OPERATION	1980

YEAR	REVENUE	OPERATING COST	DEPREC.	LOSS (IF ANY)	TAX PAYABLE	NET PROFIT	CASH FLOW
1	19.17	13.60	10.07	4.50	0.00	0.00	5.57
2	38.34	17.56	9.16	0.00	3.56	3.56	17.22
3	38.34	17.56	8.34	0.00	6.22	6.22	14.56
4	38.34	17.56	7.59	0.00	6.59	6.59	14.18
5	38.34	17.56	6.90	0.00	6.94	6.94	13.84
6	38.34	17.56	6.28	0.00	7.25	7.25	13.53
7	38.34	17.56	5.72	0.00	7.53	7.53	13.25
8	38.34	17.56	5.20	0.00	7.79	7.79	12.99
9	38.34	17.56	4.73	0.00	8.02	8.02	12.75
10	38.34	17.56	4.31	0.00	8.23	8.23	12.54
11	38.34	17.56	3.92	0.00	8.43	8.43	12.35
12	38.34	17.56	3.57	0.00	8.60	8.60	12.17
13	38.34	17.56	3.25	0.00	8.76	8.76	12.01
14	38.34	17.56	2.95	0.00	8.91	8.91	11.86
15	38.34	17.56	2.69	0.00	9.04	9.04	11.73
16	38.34	17.56	2.45	0.00	9.16	9.16	11.61
17	38.34	17.56	2.23	0.00	9.27	9.27	11.50
18	38.34	17.56	2.03	0.00	9.37	9.37	11.40
19	38.34	17.56	1.84	0.00	9.47	9.47	11.31
20	38.34	17.56	1.68	0.00	9.55	9.55	11.23
21	38.34	17.56	1.53	0.00	9.62	9.62	11.15
22	38.34	17.56	1.39	0.00	9.69	9.69	11.08
23	38.34	17.56	1.26	0.00	9.76	9.76	11.02
24	38.34	17.56	1.15	0.00	9.81	9.81	10.96
25	38.34	17.56	16.02	0.00	2.38	2.38	18.40

1980 TARIFFS	
COMMODITY ($/TON)	15.43
LIQUID ($/1000 IG)	0.00
ENCAPSULATION MATERIAL ($/TON)	
END CAP	959.84
WALL MATERIAL	959.84
DISCOUNTED CASH FLOW RATE OF RETURN (PERCENT)	8.85

* INDICATES VALUE INPUT

DISCOUNTED CASH FLOW SUMMARY ($MM)

FIXED CAPITAL INVESTMENT ($MM)	111.85
NUMBER OF YEARS OF CONSTRUCTION	3*
ANNUAL CAPITAL COST ALLOWANCE	0.09*
ANNUAL OPERATING EXPENSE ($MM)	17.56
INCOME TAX RATE	0.50*
PROJECT LIFE	25*
FIRST YEAR OF OPERATION	1980

YEAR	REVENUE	OPERATING COST	DEPREC.	LOSS (IF ANY)	TAX PAYABLE	NET PROFIT	CASH FLOW
1	24.31	13.60	10.07	0.00	0.32	0.32	10.39
2	48.62	17.56	9.16	0.00	10.95	10.95	20.11
3	48.62	17.56	8.34	0.00	11.36	11.36	19.70
4	48.62	17.56	7.59	0.00	11.74	11.74	19.32
5	48.62	17.56	6.90	0.00	12.08	12.08	18.98
6	48.62	17.56	6.28	0.00	12.39	12.39	18.67
7	48.62	17.56	5.72	0.00	12.67	12.67	18.39
8	48.62	17.56	5.20	0.00	12.93	12.93	18.13
9	48.62	17.56	4.73	0.00	13.16	13.16	17.90
10	48.62	17.56	4.31	0.00	13.38	13.38	17.68
11	48.62	17.56	3.92	0.00	13.57	13.57	17.49
12	48.62	17.56	3.57	0.00	13.75	13.75	17.31
13	48.62	17.56	3.25	0.00	13.91	13.91	17.15
14	48.62	17.56	2.95	0.00	14.05	14.05	17.01
15	48.62	17.56	2.69	0.00	14.19	14.19	16.87
16	48.62	17.56	2.45	0.00	14.31	14.31	16.75
17	48.62	17.56	2.23	0.00	14.42	14.42	16.64
18	48.62	17.56	2.03	0.00	14.52	14.52	16.54
19	48.62	17.56	1.84	0.00	14.61	14.61	16.45
20	48.62	17.56	1.68	0.00	14.69	14.69	16.37
21	48.62	17.56	1.53	0.00	14.77	14.77	16.29
22	48.62	17.56	1.39	0.00	14.83	14.83	16.22
23	48.62	17.56	1.26	0.00	14.90	14.90	16.16
24	48.62	17.56	1.15	0.00	14.95	14.95	16.10
25	48.62	17.56	16.02	0.00	7.52	7.52	23.54

1980 TARIFFS	
COMMODITY ($/TON)	20.57
LIQUID ($/1000 IG)	0.00
ENCAPSULATION MATERIAL ($/TON)	
END CAP	959.84
WALL MATERIAL	959.84
DISCOUNTED CASH FLOW RATE OF RETURN (PERCENT)	12.84

* INDICATES VALUE INPUT